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ABSTRACT

Concepts of the human environment through a systems approach are presented. Principles of systems thinking which assist the student to study subjects with a comprehensive view of the way topics are interrelated with each other, rather than considering subjects in isolation, are discussed. Part One introduces systems concepts. Part Two deals with environmental systems, including ecosystems, economic systems, political systems, and their role in the human environment. Part Three provides appendices of system notes, sources for further study and a bibliography. (RE)

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THE HUMAN ENVIRONMENT

AN INTRODUCTION TO ENVIRONMENTAL SYSTEMS

BY

DRAPER L. KAUFFMAN, JR.

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T H E H U M A N E N V I R O N M E N T

An Introduction to Environmental Systems

by

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1978

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I would also like to invite all readers of this text to share their reaction to it and their suggestions for improving it by sending their comments to: Draper Kauffman, Webster College, St. Louis, MO, 63119. If you plan to use this book in a classroom situation, please write to the above address, describing the planned use and the number of copies you will need. Additional copies will be provided free as long as they last, and thereafter at cost.

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FOREWORD

It's no secret that the world we live in is a complicated one, and that it is growing more complicated all the time. Problems like pollution, energy shortages, inflation, unemployment, crime, and urban decay affect all of us, yet it is difficult for us to know how to deal with them.

No one can be an expert on every subject. But when we turn to the experts for help, they often seem confused and isolated from the real issues, arguing with each other and looking at only those pieces of a problem that happen to fit into their own particular

specialties. Indeed, it often seems that the more people learn about the world we live in, the harder it becomes to get a real understanding of how the whole world works.

So what are we to do? Just mind our own business and ignore everything else? Unfortunately, "everything else" has a habit of invading our personal lives in a most unpleasant way if we ignore it. For example, suppose that you decide on a career that appeals to you. You spend years training for it, gaining experience, and working your way up. It's a good job and you're good at it. Then, suddenly, the job is wiped out, eliminated by economic changes, or new technology, or because it pollutes the environment, or because of a change in political priorities. These forces may be beyond your control, but if you understand how they work you can at least anticipate them and prepare to cope with them.

The same is true of all sorts of private, personal decisions. The wisdom of one choice or another depends on what is happening in the rest of our society. Furthermore we all have a stake in developing and maintaining a safe and humane environment. If we, as citizens, don't understand the big, complex problems affecting our environment, then the right decisions won't get made and we will all be worse off. (In fact, as we will see, leaving these problems to politicians and "experts" almost guarantees

that we will get solutions which don't work and which often make the problems worse.)

In other words, we all need to understand the world around us, just to survive, but we can't possibly become experts in every subject. Is there any way out of this trap? Surprisingly, there is a way--and a fairly easy way--to learn how to deal with the world around us in all its complexity without being some kind of mental Superman. The answer is an approach we can call "systems thinking," and the purpose of this book is to introduce you to it.

Expectations

Those are big claims. If "systems thinking" can do all that, why isn't it more widely known? In the first place, schools are usually slow to change the subjects they teach. This subject is still a new one and it seems quite strange to people who were trained in the traditional way. A second reason, and perhaps the most important one, is that most of what has been written about systems thinking has been extremely technical, full of mathematics, and difficult to read. Only recently has anyone made much of an attempt to translate the ideas of systems thinking for a non-expert.

And that, of course, is what this book is about. It doesn't require a background in math or science, and the jargon has been kept to a minimum. It will require a moderate amount of effort from you, mostly in

re-thinking things you already know. If you are willing to put that effort into it, here's what you can expect:

1. Learning new subjects will be easier. Most subjects are taught in complete isolation from each other. If you take a course in biology and then a course in U.S. government, no connection is made between the two and you have to start the government course from scratch. Actually, much of what you learned about biological systems applies to political systems (and vice versa); instead of having to start all over again, you can build on what you have already learned. The basic rules of how systems work apply to social systems, political systems, economic systems, ecological systems, and physical systems. Once you understand these rules you can tackle each new subject or problem by building on what you already know.
2. You will learn how to make complex problems and situations easier to understand. Most schools never deal with solving problems that cross the boundaries between different disciplines, and most people never get a chance to learn how to make messy problems more manageable. Taking a systems approach to such problems doesn't guarantee right answers, but it does increase your chances.

3. You will get some suggestions about effective strategies for influencing the world around you. When people see things they want to change, they often spend their efforts in ineffective ways, and they get very frustrated as a result. A systems approach can help you identify "high leverage points" in the systems where your efforts will have a greater chance of success.
4. Finally, you will get some help in developing a comprehensive world view of your own. Both in school and out, most people are exposed to knowledge in bits and pieces and get very little help in tying these chunks together into an overall pattern that makes sense. Whether you can create such a pattern for yourself over the years is largely up to you, but a systems approach at least provides a consistent frame of reference and a way of fitting the pieces together as you come to them.

PART ONE

INTRODUCING SYSTEMS

Chapter One: WHAT IS A SYSTEM?

For many centuries scientists believed that the best way to learn more about something they didn't understand was to take it apart and find out what it was made of. This approach had been quite successful, particularly in biology, chemistry, and physics. However, there is always the danger when anything is successful that people will want to take it too far. In this case, the extreme is called "reductionism"--the idea that something is "nothing but" the sum of the parts. This sounds reasonable, but it leads to the illogical conclusion that there is no difference between a comfortable house and a pile of building materials, or between a frisky mouse and a test tube full of chemicals.

The difference, of course, between the molecules in a mouse and those in a test tube full of chemicals is organization. The molecules in a mouse are organized in a precise and extremely complex way, while those in the test tube are just sloshed together. Most scientists realized that it was important to understand how the pieces fit together, at least in their own field, but they were still mostly concerned about the "parts" rather than about the "pattern."

"...molecules in a mouse are organized..."

One of the results of this attitude was the division of the sciences into many different specialties. Because the basic units of each subject are so different, it seemed that the ways these units were organized must also be unique, and that various specialties therefore had little in common with each other. The result was that the experts in each speciality developed their own specialized theories and their own specialized languages to describe them. Eventually, this meant that scientists in different fields could no longer understand each other and that the public couldn't understand any of them without years of study.

Then, beginning in the 1920's, a group of researchers

began seriously to study the patterns themselves, the ways in which all different kinds of "systems" were organized. And they made a startling discovery: no matter how different the ingredients of different systems looked, they were all put together according to the same general rules of organization! For the first time, there was a way of linking together all of the scattered fields of knowledge and showing what they had in common.

This new field, which is known as "general systems theory," began to have a powerful impact almost immediately. It has revolutionized many fields of science and has had an enormous impact on all our lives, even though most people have never heard of it. Among other things, it made possible the development of sophisticated computers and automation, and its practical application as "systems analysis" is an essential tool for the management of all kinds of businesses and institutions.

Its two most important contributions are only now being realized, however. The first is that systems theory provides a way of tackling those big, messy, real-world problems which don't fit neatly into various specialities, just at a time when we face a whole batch of problems so serious that they threaten the survival of our society. The second is that general

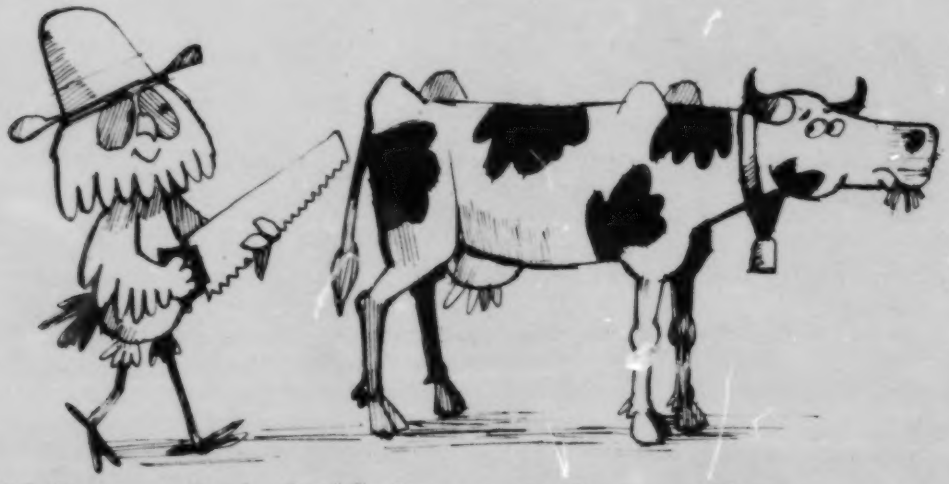
systems theory provides a way for average people to get a good, clear picture of how their environment works without spending their lives studying all the details of every subject.

The Idea of "System"

A theory of how systems work has to begin, of course, with an idea of what a system is. Fortunately, we are going to use the word "system" in its everyday sense, as in "nervous system," or "legal system," or the "cooling system" in a car. In other words, a system is a collection of parts which interact with each other to function as a whole. The cooling system in a car, for example, may consist of a radiator, a fan, a water pump, a thermostat, a cooling jacket, and several hoses and clamps. Together, they function to keep the engine from overheating, but separately they are useless. To do the job, all of the parts must be present and they must be arranged in the proper way. Moving one end of a hose just an inch is enough to put the whole cooling system (and the car) out of commission.

If something is made up of a number of parts and it does not matter how those parts are arranged, then we are dealing with a "heap" and not a system. (A pile of sand, for example, remains essentially unchanged even if you stir it around and change the location of specific grains of sand.) Another difference between "systems" and

"heaps" is that "heaps" are not essentially changed by adding to the size of the heap or taking some parts away from it. Adding more milk to the milk already in a pail just gives you a larger amount of milk, but adding another cow to the one you already have does not give you a larger cow. In the same way, pouring half the milk into a second pail gives you two smaller amounts of milk, but dividing the cow in half does not give you two smaller cows. You may end up with a lot of hamburger, but the essential nature of "cow"--a living system capable, among other things, of turning grass into milk--would be lost. This is what we mean when we say that a system functions as a "whole": its behavior depends on its entire structure and not just on adding up the behavior of its different pieces.



"Dividing a cow in half does not give you two smaller cows."

This brings up a logical question: if the pieces of one system act together like a single unit, why can't that system be a "piece" of some other system? The answer is that it certainly can be part of a larger system. If it is, we call it a "subsystem" of the larger system. And that larger system, of course, can be a subsystem of a still larger system. In fact, this pattern of systems being part of larger systems which are part of still larger systems, and so on, is something we will find wherever we look, in all parts of the human environment.

For example, since we have been talking about cows, let's take a look at the chain of smaller and larger systems which the cow belongs to. A cow, like any living thing, is a very complex system in its own right, but it is also part of a number of larger systems. If it is kept with other cows, it will be part of a highly organized social system called a "herd." Each herd has a leader ("Bossie") and a chain of command as clearly defined and strictly enforced as in a military unit. If we are primarily interested in learning how a herd works, then we think of the herd as the basic system and each of the cows as a subsystem of the herd.

On the other hand, if we are primarily interested in learning how a cow "works," we would treat the cow

as the basic system and try to learn something about its subsystems--such as its circulatory system, nervous system, reproductive system, and digestive system--and how they work together to enable the cow to stay alive and do the various things that cows do. In fact, we can continue this process of looking at smaller and smaller subsystems until we get clear down to the level of atomic particles.

The illustration on the next page shows how such a "ladder" or "hierarchy" of systems would look if we started with one particular atom in one cell of your own brain and worked our way up from there as many levels as we can go.

Each system on the list combines with other systems of about the same level to make up the next larger system. Thus a particular protein molecule might contain atoms of carbon, hydrogen, oxygen, and nitrogen; an economy is made up of people, land, buildings, machines, plants, dairy herds, and so on; and the solar system is made up of the sun, the planets and their moons, and many, many asteroids, comets, and other bits of debris. If we had started at a different point--say, for example, an atom in a cow's brain--our list would have looked a little different in the middle, but it would still consist of a similar set of steps, with smaller systems combining to make

Increasing Size

Universe
Galaxy
Solar System
Planet Earth
World Ecosystem
World Civilization
Nation
State
Local Community
Individual (YOU!)
Nervous System
Brain
Brain Cell
Cell Nucleus
Molecule
Atom
Particle

larger systems which combine with others to make still larger systems.

Why is this true? If you stop to think about it, this neat progression of steps, from the smallest particle up to the entire universe, does seem rather odd. Why doesn't nature just make larger particles, instead of building atoms up out of small ones? Why not just have larger and larger atoms, instead of

building molecules up from combinations of atoms? For that matter, why are you composed of many billions of cells instead of being one super-giant-sized cell?

Systems and Stability

It seems that the reason in every case is that a collection of smaller units--a system--is more stable than one large unit. For example, protons and neutrons are the largest particles that exist in nature. Physicists have made bigger particles experimentally, but these are so unstable that many of them last less than a billionth of a second before they disintegrate. Similarly, atoms bigger than a certain size become more and more unstable. (Uranium, the heaviest natural element, is radioactive because its atoms are constantly breaking down into smaller, more stable elements, a process which gives off radiation; man-made elements like plutonium, which are even heavier than uranium, are even more unstable.) A cell larger than a certain size would simply die of suffocation, unable to move oxygen and food in, or waste products out, fast enough to stay alive.

The same thing is obviously true of the maximum size of animals: anything much bigger than a whale or a dinosaur would have a hard time finding enough food to keep going, much less coordinating its entire

bulk efficiently. And it is easy to see how this works with social organizations. A group of five people can work together as a single team, but a group of five thousand people would find it almost impossible to get anything done without dividing up into smaller working groups and organizing some way of communicating between those groups. In other words, a group that big is just a disorganized crowd or mob unless one or more higher levels of system organization are created.

Furthermore, even if oversized low-level systems were possible, it would still seem simpler to use a series of higher levels. There are millions of possible molecules, but instead of millions of different kinds of atoms, nature needs only 92. And instead of 92 basic particles, there only have to be 3--protons, neutrons, and electrons. For a living organism, too, it is much simpler to carry the "blueprints" for a few basic kinds of cells and another blueprint for how those cells will fit together, than it would be to try to carry a blueprint for the entire organism. And it is obviously much simpler for a society to have one set of basic rules which apply to all families, for instance, than it would be for it to try to create completely different basic rules for each individual family.

Ever if we accept the idea that systems of a

particular level become unstable as they grow beyond a certain point, we still have not established why it is that a higher level of system organization can be any more stable. In fact, there is a good reason for this stability and it goes back to our original definition of what a system is. If you remember, it said that a system is a collection of things which interact with each other to function as a whole. The key word here is "interact." If one part has an effect on the rest of the system and the system as a whole has an effect on that one part, then a "circular" relationship--or "loop"--has been created.

For example, you and a bicycle together form a simple, two-part system. Combined, you can do things which neither you nor the bicycle can do separately. Furthermore, your actions have an influence on what the bicycle does and the behavior of the bicycle has an influence on your actions.

Now, the interesting thing about even such a simple system as this one is the way it creates stability out of a situation which would normally be very unstable. If you climb on the bike and do nothing, neither you nor the bike will stay upright for very long. In fact, if you climb on the bike and do the wrong things, you will still end up on the pavement with a thump.

What is happening, when you ride a bicycle,

skillfully, is that you are constantly making small adjustments to correct for "errors" in the path and the balance of the bicycle. If the bicycle starts to turn or tilt one way, you shift your balance or steer in the other direction. If it goes too far the other way you nudge it back again, and so forth, thus keeping it

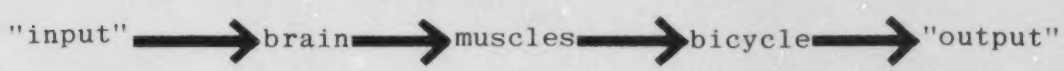
"The rider is constantly making small adjustments"

upright and on course. In fact, even if it looks like you are riding in a straight line, you are actually making a constant series of wiggles from one side to the other as the bike moves slightly off course and you correct for it, over and over again. Sometimes it is easier to see this pattern if you slow way down, or watch someone who is just-learning to ride--in either case, the wiggles will

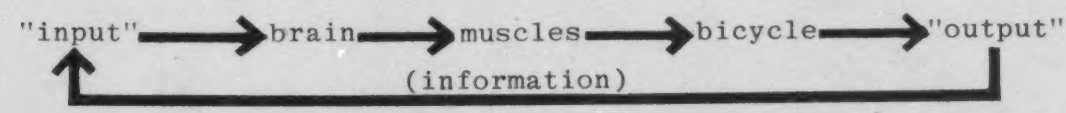
be quite a bit larger. As you speed up or grow more skillful, your corrections become smoother and less obvious.

To ride a bike properly, you need information about where the bicycle is and which way it is tilting, information you get from your eyes, your muscles, and the balance tubes in your ears. Without a continuous flow of this information, you would find it difficult --if not impossible--to ride the bicycle at all. (Just think how hard it would be to ride a bicycle with your eyes shut!)

Here's how we could diagram such a system:



In other words, your brain tells your muscles what to do, your muscles push against the bicycle, and the bicycle responds by moving. The "input" is the information you had which caused you to decide to use your muscles the way you did, and the "output" of the system is the motion of the bicycle and yourself. But now, after you start the system moving, there's a new situation and a new position for the bicycle, which provides new information for your brain to work with. In other words, a new line should be added to our diagram:



In this way, information about the output of the system is fed back around to the input side of the system. Information that is used this way is called "feedback," and any system like the one diagrammed above is called a "feedback loop."

Can you see now how this feedback provides stability in a system that would otherwise be unstable? Your brain receives information about where the bicycle is and compares that with where the bicycle should be. If there is a difference between the two for any reason--whether it's because you made a slight error or because the environment has changed--your brain tells your muscles to act in such a way that the difference will be eliminated, thus bringing the system back on course. Because this kind of system acts to cancel out or "negate" any changes in the system, it is called a "negative feedback" loop.* This idea of negative feedback seems simple but it is extremely important for understanding the systems in our environment. As we will see in the next two chapters, these negative feedback loops occur by the thousands inside us and all around us.

*Unfortunately, the phrase "negative feedback" is sometimes used loosely as a synonym for "criticism," particularly in education. When talking about systems try to keep in mind that negative feedback isn't necessarily good or bad. It is simply a process which negates changes or disturbances in the system.

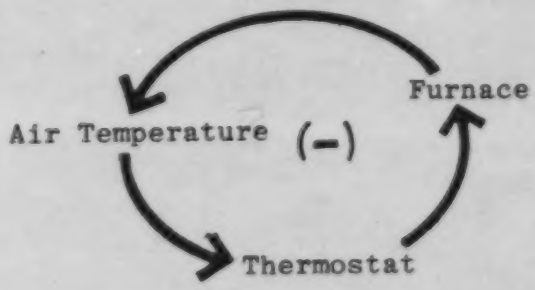
Chapter Two: STABILITY

The world around us is full of change. The physical environment on earth is one of continuous change in temperature, radiation, moisture, windspeed, and so on. Even the surface of the earth itself is constantly changing, with sea beds being thrust up to make mountains, and mountains constantly being worn down again. Any system which is going to survive long enough to be an important part of our environment has to have the ability to cope with that kind of change and survive it. All stable systems get this self-stabilizing ability from negative feedback loops.

In other words, negative feedback loops are everywhere, in every part of our natural and social environment. If we understand how they work, we will have a tool that will help us understand all kinds of systems.

The easiest way to get a feel for how negative feedback works is to look at a number of different examples from different kinds of systems, which is what we are going to do in the rest of this chapter. Then, in chapter 3, we will have a look at some principles, or rules of thumb, which you can apply to all systems that have negative feedback.

The Thermostat: One of the most common mechanical feedback systems is the heating system found in most homes and buildings. Once a temperature has been set on the thermostat, the system will try to keep the temperature in the house as close to that level as possible. If the temperature drops below that level, the thermostat responds by turning the furnace on. The furnace produces heat, which warms the air back up. Eventually, the temperature rises above the desired level and the thermostat shuts the furnace off. Then, if it is colder outside than inside, the house will cool down again until the thermostat turns the furnace on, and the whole cycle is repeated. A diagram of the feedback loop looks like this:



Following the arrows, this diagram says: "The furnace controls the air temperature, the air temperature controls the thermostat, and the thermostat controls the furnace." In addition, the minus sign in the middle tells us that this is a negative feedback loop, so that changes will be cancelled out--a drop in the air temperature will be followed by a rise in the air temperature, and a rise will be followed by a drop.

The nice thing about this system is that it responds automatically to changes in its environment. If it warms up outside, the thermostat shuts the furnace off and keeps it off as long as the air inside is at least as warm as it should be. If it cools down just a little outside, the house will cool off slowly and warm up quickly, so the thermostat will keep the furnace on for only a few minutes every hour, just enough to make up the difference. But if it gets really cold outside, the thermostat might have to keep the furnace running nearly all the time. The result is to keep the inside temperature stable, regardless of how the temperature outside drops.

What about hot days? A heating system can't do anything to keep a house cool, but at least the thermostat can shut the furnace off and keep it from making the house even hotter. Of course, we could add an air conditioner to the system and connect it to the thermostat. Now, if we set the

heating system for 70 degrees and the cooling system for 78 degrees, the thermostat will turn the furnace on if the temperature drops below 70 degrees and the air conditioner on if it rises above 78 degrees. This changes a one-directional feedback system which keeps us from getting cold into a two-directional system which will keep the house comfortable in any weather.

Thermostats are cheap to make and save people a lot of effort, so they are found in many different places. Have you ever noticed how, if you open the door of the refrigerator when the motor is off, the motor usually starts up again after a few seconds? That's because opening the door lets warm air in, and the thermostat inside the refrigerator senses the change in temperature. Thermostats keep the water in a water-heater hot and the water in a water-cooler cold. Thermostats are also found in most electric stoves, in the cooling systems of most automobiles, and in many other places.

Body Temperature: The thermostat in your house is a human invention, of course, but the original thermostat was invented by nature several hundred million years ago. To begin with, animals had no way to control the temperature of their own bodies. Many of the simpler animals, like the reptiles, are still like this. They can move fast when they are warm, but they slow way down when the weather gets cold,

and they get overheated and die when the weather gets too hot. Over the years, however, some animals developed "thermostats" for keeping their body temperatures the same in spite of changes in the outside environment. Being "warm-blooded" was a big advantage, especially in cold weather, so these animals gradually developed more and more efficient systems for temperature control.

Human beings are warm-blooded, of course, and our temperature control systems are usually quite accurate. Most people have bodily thermostats that are set for around 98.6 degrees. If your body temperature starts to fall below that, your thermostat makes a number of things happen. First, it turns up your "furnace" causing you to burn fuel (food) faster, thus creating more heat. Then it will start you shivering, which makes your muscles work harder even when you are not doing anything, and that creates even more heat. And while these and other things are going on, your body sends a message to your brain saying, "I'm cold!", and you start looking

"It turns up your 'furnace', thus creating heat."

around for hot food, heavier clothes, or a warmer location. Similarly, if you get too hot, you start to sweat, the blood vessels under the skin expand so that your blood can carry body heat to the surface more quickly, and you are likely to get a strong urge to slow down, loosen your clothes, and find a cold drink and a spot in the shade.

Either way, the system keeps the temperature in the middle of your body nearly constant. Even when you feel so hot or cold that you can barely stand it, your body temperature rarely changes more than half a degree (unless you get sick). The feeling of being too hot or too cold is part of the feedback loop, and what it actually tells you is how hard your body is working to control its temperature. So when you say, "I'm cold!", what you really mean is, "My body is having to work too hard keeping me warm!"...and vice versa.

Float Valves: Another kind of simple, self-regulating machine was probably invented long ago by a farmer to keep a pond from either flooding or drying up. What this early genius did was to pivot a stick in the middle, fasten one end to a chunk of wood floating in his pond, and fasten the other end to the gate or valve which let water into the pond. Then, whenever the water level in the pond dropped, the float pulled one end of the stick down, which pulled the other end up, which opened the gate and let more water in.

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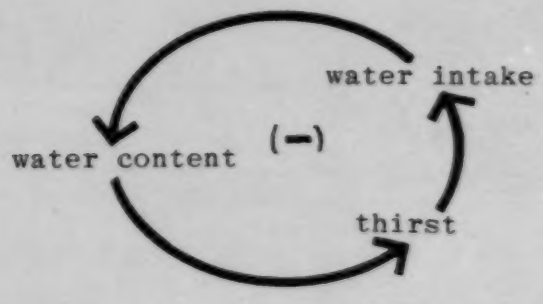
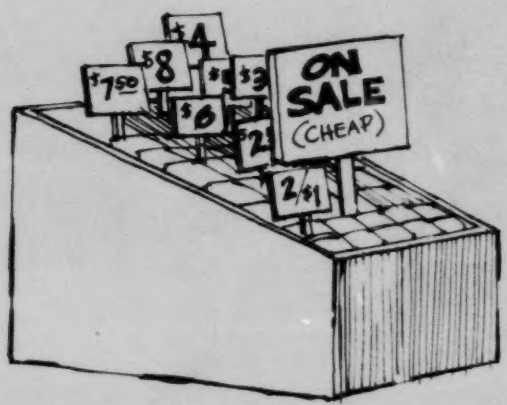
Thirst: People, and other living things, don't have float valves inside them, but they do have systems which control the amount of water inside them. Water is essential to life, and it is constantly being used up to flush wastes out of the system and, for many plants and animals, to help with cooling. We are all familiar, of course, with the way this feedback loop works in human beings: when the water content of your body drops too low, you get thirsty! (Oddly enough, we don't have a similar word for the feeling which tells us to stop when we've drunk enough water, even though the feeling is unmistakeable. Try drinking three straight glasses of water when you aren't at all thirsty--it really is quite unpleasant!) Even though the "pieces" of the thirst system are very different from the "pieces" that make up a float-valve system, the two systems do the same job using the same negative feedback loop arrangement:



Inventories: The manager of a store faces a similar problem in controlling the supply of things he has for sale. He doesn't want to get stuck with boxes of things which no one wants to buy, because that way he loses money. On the

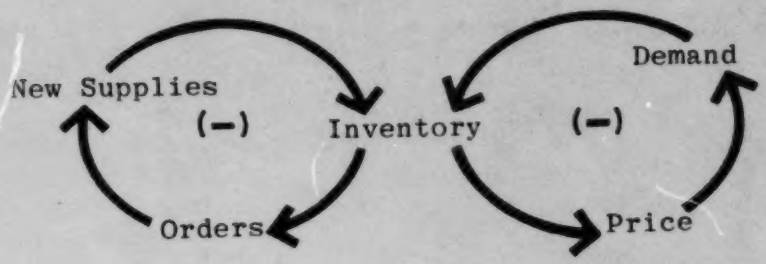
other hand, he doesn't want to run out of things that people want to buy, because then they will go to another store and he will lose money this way as well. So a good manager has to keep a very careful eye on his stock. If something sells more slowly than expected, he must quickly reduce or cancel his orders for it before it piles up on his shelves. If it is really unpopular, he may find that he has to reduce the price to get people to buy it. He might even have to sell it for less than he paid for it, just to get rid of it and make room for other things he can sell at a profit.



"He may find he has to reduce the price to get people to buy it."

On the other hand, if something proves more popular than expected, he has to place additional orders quickly before he runs out. If it is something that takes a long time to receive after it is ordered, and he realizes that he is going to run out anyhow, he may decide to <u>increase</u> the price so that fewer people will want to buy it. If he guesses right on how much to raise the price, his stock should just last until the new supply arrives. (In addition, of course, he will make more money on each item, which he can use to make up for the money he lost on other items which he had

to put on sale.) Because the manager has the choice of adjusting either his orders or his prices (or both), the diagram here is a little more complicated:

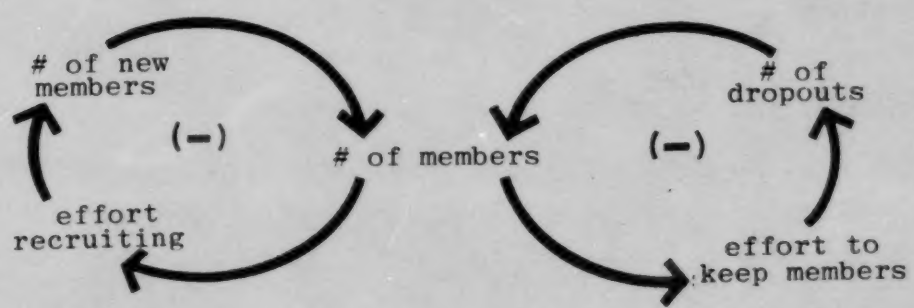


This is an example of a basic negative feedback relationship in economics. It is called the "law of supply and demand" because it works to keep a stable balance between the supply of something and the demand for it. If the supply is larger than the demand, the feedback cycles work to reduce the supply (cancelling orders) or increase the demand (by reducing the price), or both, until supply equals demand. And if the demand is greater than the supply, it works to reduce the demand (by increasing the price) or increase the supply (by placing new orders), or both, until the two are equal again.

Group Membership: A similar pair of feedback loops helps to maintain the stability of a lot of social organizations. For example, many kinds of social groups need some minimum number of members in order to function properly. A church needs a big enough congregation to pay the minister's salary

and the upkeep on the church property. A P.T.A. needs enough members to serve on its committees and to meet with school administrators and school board members. A social club or a scout troop needs enough members so there will be plenty of people to have fun with. A basketball team needs enough players to keep at least 5 on the floor, even if some get hurt or winded or thrown out. And so on.

Any group like this has to recruit new members to replace those who die, move away, find other interests, or simply get bored and drop out. If the people wanting to join the group are enough to replace those who leave, there is no problem. But if more people quit than join, the size of the group will drop and the remaining members will begin to get worried. They may organize a membership drive, advertise their group, go out and try to talk people into joining, make the group easier to get into, or try to make membership in the group more appealing to new people. On the other hand, they might try to find out why old members are leaving the group so that they can reduce the drop-out rate. If either or both of these efforts are successful, the membership of the group



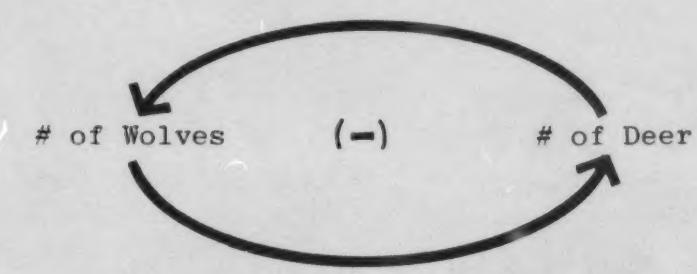
will rise again until it is safely above the minimum level, at which point the special recruiting activities can be reduced. The result is a negative feedback process which keeps the number of new members joining the group approximately equal to the number of old members leaving the group, and which therefore keeps membership of the group approximately stable.

Predators and Prey: The examples above concern human communities, but the basic ideas apply to other kinds of communities as well. A natural ecology is a community of plants and animals, like a forest, a swamp, a meadow, or a lake. The relationships between the different living things in these natural communities are kept in balance by the same kinds of negative feedback loops which keep human communities stable. One of the most important of these loops is found in the relationship between predators (animals which eat other animals) and their prey (the animals they eat), and the way that this relationship keeps the populations of both the predators and the prey animals fairly stable.

For example, in some areas the deer and the wolf have a close relationship. If something happens (like an exceptionally cold winter) to reduce the number of deer in an area, the wolves will find it harder to find food. Old or injured wolves which might have survived will die, younger wolves will move out of the area to look for a better food supply, and many wolf cubs will die of hunger and disease.

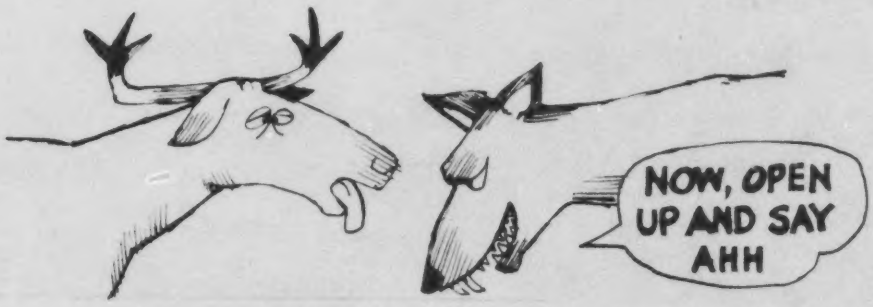
But now there are fewer wolves for the deer to have to worry about, so many more of the young deer will survive than would have normally. When these deer grow up, there are more parents than normal, and these extra parents produce an even larger number of new fawns (baby deer). If the winter is mild and other conditions are good, this soon creates a rapid increase in the deer population, But, as the supply of deer increases, the wolves find it easier to catch food. Wolves that would have left or starved are now able to remain and stay healthy. Pretty soon, with so many wolves around, the deer find it a lot harder to keep from being caught. When the wolf population gets large enough, it actually begins reducing the deer population.

Eventually, with too many wolves and not enough deer, the wolves will begin starving again. This reduces the wolf population, which lets the deer population start growing again, and we are back where we started from. The result is a simple negative feedback loop which works like this: more deer means more wolves, which means fewer deer, which means fewer wolves, which means more deer, which means more wolves, and so on.



Incidentally, if you think this system is hard on the deer, it really isn't. The wolf is actually essential to the health of the deer population. If you went out and shot all of those "big bad wolves" the deer would soon be much worse off. For a while, their numbers would grow very rapidly, but sooner or later they would reach the point where there would be enough deer to eat up all of the food available in their environment. If this happened, an enormous number of deer would starve to death, and it might even wipe out the entire population.

Even if hunger were not a problem, disease would be. Normally, the wolves catch very few healthy, adult deer, but they do eliminate most of the animals that become sick. Without the wolves, the sick deer would pass their diseases along to the rest of the deer. If the population has grown to the point where the deer are quite crowded, the chances of one deer passing a disease along to another increases



"The wolf is actually essential to the health of the deer"

greatly, and it is possible for an epidemic to sweep through the entire deer population. The wolves prevent this by thinning the herd and killing off the sick ones before they can infect the others. So, strange as it may seem, eliminating the wolves would be bad for the deer!

The way in which this negative feedback process works may seem cruel, but the stability which it provides is essential to the well-being and survival of both the wolves and the deer. In fact, similar relationships exist which involve all living organisms and which give natural ecologies the stability people refer to when they talk about the "balance of nature."

Tracking Systems: So far we have been talking about systems which "aim" at a fixed "target." A heating system "aims" at whatever temperature is set on the thermostat. A social group "aims" at maintaining a membership level which is sufficient for its particular activities. But systems can also be set up to follow or "track" a moving target. In fact, the principle is really the same. The system gets feedback on how far it is from where it should be and uses the feedback to try to reduce the difference. It doesn't matter to the system whether the difference comes from a change in the system or a change in the target--it just senses a difference and tries to reduce it. For example, you can save energy by turning your household thermostat down five or ten degrees at night and turning it back up again when you get up in the

morning. The negative feedback loop in the heating system causes it to "follow" each change, down to the lower temperature during the night and up to the higher temperature during the day.

A similar system can be used to keep solar energy collectors aimed at the sun. Tracking collectors usually gather the sun's rays from a large area and focus it onto a smaller area. As the sun moves across the sky, the point at which its rays are focussed gradually slips away from the target area. One common solution is to put a ring of "sensors" around the target area and hook them up so that when the sun hits a sensor on one side of the target, it causes the target to shift in the opposite direction. In this way, the collector tracks the image of the sun across the sky throughout the day.

A thermostat or solar collector tracks its target rather slowly, but tracking systems can also be created which work much faster and more accurately than a human being could. The military used this approach during World War II to design radar-controlled anti-aircraft guns which could "lock onto" an enemy airplane and follow it at high speed. Similar aiming systems are now used in guided missiles and a variety of other weapons, as well as in more peaceful systems, such as the one which the astronauts use to link up to space vehicles. In fact, it is now possible to design very complex automated machines, and even whole

automated factories, using high speed computers to control thousands of negative feedback loops at the same time.

The tracking systems which we have considered so far have one thing in common: someone has figured out a way to make the gadget do the entire job, without depending on constant human control. However, most tools and machines still require people to provide feedback and guidance for the system. As a general rule, we replace these human/mechanical systems with all-mechanical ones only when the job is so simple and repetitious (like controlling a furnace) that a reliable, inexpensive machine can do it, or when the job is so difficult that a human being cannot do it effectively (like tracking a high speed jet).

In a human/mechanical system, the human being usually takes the place of the control unit. For example, it is the rider, not the bicycle, which receives the information about the progress of the rider-bicycle system and decides what to do next. The same principle applies to all vehicles--cars, boats, planes, roller skates, surf boards, etc.--as well as other systems requiring "coordination," ranging from hitting a nail with a hammer or a baseball with a bat to eating with a fork or writing your name.

Most of these need no further discussion, since they all work the same way as the bicycle-rider system we have already analyzed. The person in charge starts the system moving and then guides it with a series of corrections

to keep it following the desired path. But the system works so fast and so smoothly in some cases that it doesn't seem possible that there is time for the negative feedback process to happen. If you swing a bat at a baseball, you don't stop every inch and measure the position of the bat and decide where it is going to go next; you just swing it, don't you? Even though it feels that way, high speed photographs and careful measurements have shown that you make dozens of tiny corrections with the muscles in your arm, wrist, and fingers in the fraction of a second it takes the bat to reach the ball.

If you doubt this--and it <u>is</u> a little hard to believe--try closing your eyes just before the start of each swing. You may hit the ball a few times, but the odds are that you will miss it much more often than you hit it. (That's why the coach is always saying, "Keep your eye on the ball!")

"Try closing your eyes before the start of each swing."

Tracking systems are also common in natural and social systems. A sunflower tracks the sun across the sky just like a solar collector, and a bat tracks a flying bug with the precision of a guided missile. Politicians quickly learn to track changes in public opinion if they want to be re-elected. Companies learn to track changes in public buying habits, or they go broke. And so on. In other words, tracking systems crop up wherever systems have to aim at a moving target rather than a steady one.

It may be helpful at this point to summarize the examples of negative feedback that we've discussed so far. The list below divides the examples into categories and suggests some other uses of negative feedback in each category. Don't worry about the ones you aren't familiar with; instead, see if you can work out the feedback loops for the ones you do recognize, and try to think of additional examples in each category.

Mechanical systems

Already mentioned: Thermostat, float valve, solar tracker radar-controlled gun, space vehicles.

Other examples: Cruise-control on a car, automatic pilot on a plane, automatic frequency control (AFC) on FM radios, governor on a steam engine or other machine, ship stabilizers; can you think of more?

Human/mechanical Systems

Mentioned: Vehicles, bat, hammer, writing, eating

Others: All non-automatic tools and machines

Biological systems

Mentioned: Body thermostat, thirst/control of water content, sun tracking, bug catching.

Others: Breathing reflex (oxygen and CO_2), hunger, blood sugar, balance, pain avoidance, blood pressure, blinking, iris size, sleep, muscle-building, blood chemistry, healing. Can you suggest others?

Ecological Systems

Mentioned: Predator/prey, population/food, population/disease.

Others: Population/stress, plants/CO_2 balance, ecological succession (healing); see chapter 7 for more.

Social Systems

Mentioned: Group membership, supply and demand, politicians/public opinion; companies/buying habits.

Others: Friendship, football strategy, disaster relief, elections, markets, bankruptcy, independent courts, free press; see chapters 8 and 9 for more on economic and political systems.

These are just a few examples of the way that negative feedback provides stability in all kinds of systems and in all parts of our environment. Although change is all around us, the result of change is not chaos. The reason is that we are also surrounded by systems which are able to cope

with change, using negative feedback to control it. There are many thousands of these self-stabilizing systems at work in your own body right now to keep you alive and functioning. Your blood alone contains hundreds of chemicals--oxygen, carbon dioxide, water, salts, sugars, enzymes, fats, minerals, hormones, etc.--each of which is regulated by one or more loops. And other natural and social systems depend on negative feedback just as much for their survival.

Chapter Three: THINGS IN COMMON

Because negative feedback is so universal, it makes all sorts of different systems behave in certain similar ways. In this chapter, we are going to take a look at some of these so that you will have a better idea of what to look for when studying the systems around you.

Active Systems: One important thing about self-stabilizing systems is that they make an active response to change. They don't just sit there and ignore pressures on them. If you prop a bicycle up on its kickstand and a breeze comes along, the bicycle won't do anything by itself to increase its own stability. If the breeze gets strong enough, it

knocks the bicycle over. If you are riding the bicycle, however, and a cross-wind comes up, you can simply lean into the wind, pushing against the pressure. Other active systems work the same way.

But an active response to change requires the use of energy. Sometimes a system gets the energy it needs from the same outside forces which are trying to change it. For example, the most common type of wind generator uses the power of the wind itself, pressing against the tail vane, to keep the wind generator facing into the wind.

Other kinds of systems get their energy from different places, and many of them are able to store a certain amount of energy for a while. For example, living systems draw energy from sunlight or food and store the energy for later use. Some mechanical systems can also store energy--like the gas in a gas tank or the electricity in a battery--while others can be plugged into a wall socket which connects to the electric company's storage system.

Almost all living systems are also active in another important sense: they continue to function and to use energy even when they do not need to respond to their environments. Mechanical systems, like a car or a furnace, can be switched completely off for a while and then turned back on again. The same is true of some very simple living things. Some plant seeds can wait for decades for the right conditions

to start growing and some microscopic animals can be frozen solid and then be brought back to life.

But most living things must stay active; if they ever completely stop, they die. When you sleep, it is like letting a motor idle, not like switching it off. Your heart still beats, you breathe, your stomach digests food, your muscles move, your cells perform their complex chemical tasks, and your brain keeps up constant electrical activity. And when you are awake, a lack of stimulation from your environment will soon make you feel bored enough to actively seek or create some kind of stimulus.

As a general rule, the more complex a system is, the more energy it must spend just to maintain itself and the more active it will be about initiating changes in its environment. A worm uses more energy for maintenance than a cabbage, a frog uses more than a worm, and a cat uses more than a frog. The cat is also much more active in seeking and creating stimulation, spending a great deal of energy on satisfying its curiosity and on play activities.

Is the same thing true of social systems? It seems to be. Just compare the economy of an isolated peasant community, where everyone keeps track of his own affairs, and a modern ecomony, with its banks, bookkeepers, accountants, computers, contracts, lawyers, corporations, stock markets, and its profusion of "frivolous" and playful products and services. Or compare a large national government with the

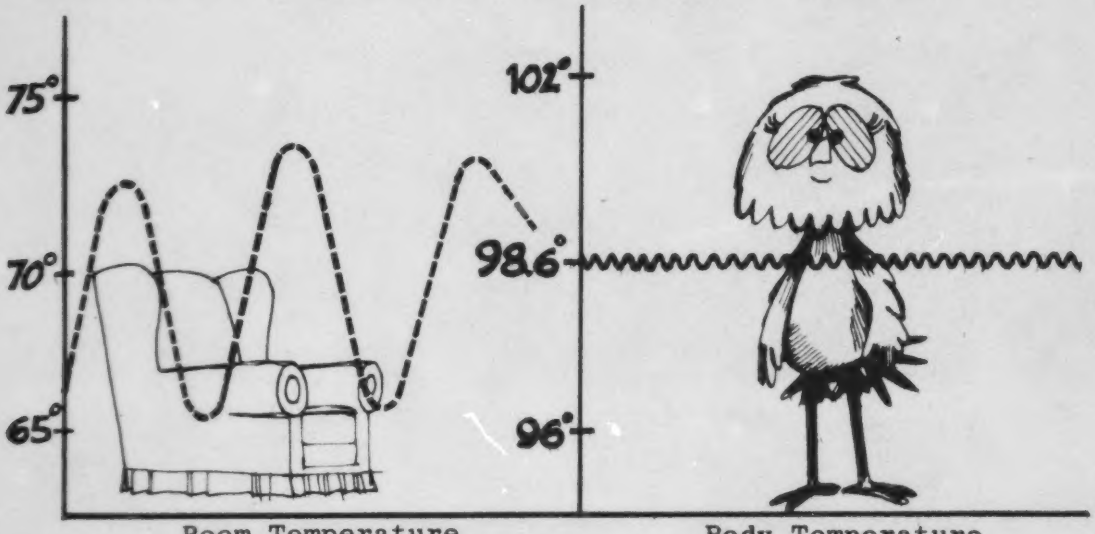
political structure of a neighborhood club. In both cases, the more complex system has to spend a higher proportion of its energies on processing information and maintaining itself, and it generally has a higher level of internal activity (compared with its environment) than the simpler system. A club can even stop functioning for a while and start back up again, while a society obviously has to keep going all the time.

System Limitations: There are limits to the amount and kind of change which any active system can deal with. One kind of system failure occurs when a heavy stress on a system continues for a long time, and the system's reserves are exhausted. For example, you store up energy in your body and then use it gradually over a period of time. If you are in a cold place, your body will use that energy to keep your body temperature up. But if you stay out in the cold too long, all of your energy reserves will be used up and your temperature control system will simply stop working. Even though you are cold, you will stop shivering and feel warm, but you will soon lose consciousness and die if you are not warmed up quickly. This is what happens when people die of "exposure."

Similarly, your body temperature will stay stable even when the air gets extremely hot...but only for a while. When that limit is passed, your temperature control system

quits, you stop sweating, and your body temperature soars. This is called "heat-stroke" and it is fatal unless immediate steps are taken to cool you off. Many negative feedback systems are like this; they are very stable over a wide range of conditions, but fail abruptly when pushed beyond their limits, so it is important for us to learn what those limits are.

Sloppy Systems: Another characteristic of self-stabilizing systems is that negative feedback does not prevent change. It just responds to change and keeps it under control. The result is that characteristic "wobble" in the system's behavior, as the system moves away from its target condition, pulls itself back, moves away again, pulls itself back, and so forth. In some cases, the wobbles are so small that they are hard to detect, but they are always there. In other cases, they are large enough to be obvious at a glance, giving these systems a definitely "sloppy" appearance.



TWO THERMOSTAT SYSTEMS

Sloppy systems are not necessarily bad; they are often cheaper and sturdier and better able to cope with large changes in the environment than more precise systems. For example, an ordinary thermostat can keep the temperature in a house from changing more than 5 or 6 degrees and costs around $30, but a super-accurate system which can keep the temperature of a special laboratory from changing more than a tenth of a degree costs more than $100,000.

Another example is one you can demonstrate for yourself in just a few moments. First, trace a circle on a piece of paper. Then find a pair of scissors and cut the circle out. Sooner or later, as you cut, you will see the scissors slipping away from the line you are trying to follow. Naturally, when this happens, you guide the scissors back again toward the line, and so on, with each change of direction leaving a bit too much or too little paper along the edge of the circle. As long as you don't mind a certain amount of this roughness you can cut the circle out quite quickly and easily. But if you decide that you want an extremely precise job done, you will find that it takes much more time, effort, and concentration. Even then, if you examine the edges of the circle carefully when you are finished, you will find that there are still tiny points and flat spots around the rim of the circle.

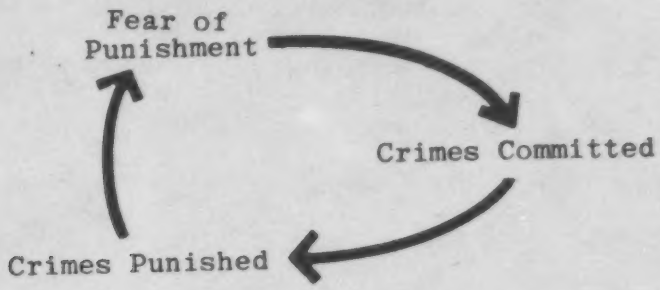
Sometimes the attempt to make a sloppy system more

precise does much more harm than it is worth. For example, even the closest friendship is never perfectly harmonious. Occasional conflicts are inevitable, but not fatal, as long as the friends are willing to find ways to adapt to each other. But we all know of "doormats"--people who try too hard to please. Because they can't stand even a slight conflict, they back down at the first sign of disagreement, disguise their own feelings, and let other people walk all over them. In short, they try to eliminate conflict by adapting "perfectly" to others, and the usual result is to make their friendship not worth having.

We all Know "Doormats"

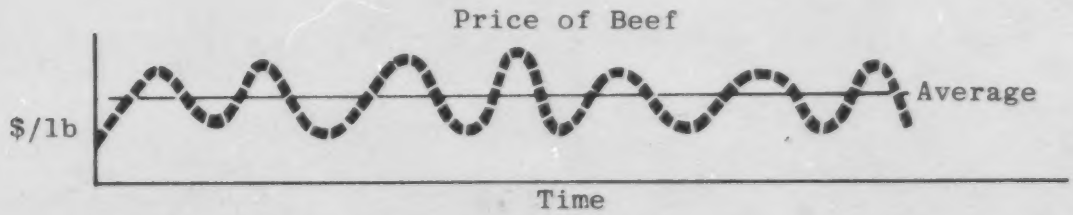
Can you think of any other examples? How about the way we handle crime in our society? As it is now, we wait until after a crime has been committed, and then try to

catch and punish the criminal, hoping the fear of punishment will keep most people from committing crimes.



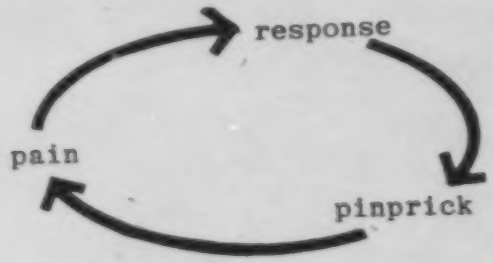
Wouldn't it be better to prevent all crimes from happening in the first place? But in order to do this we would have to have some way of watching each person in the society all the time. The cost would be ridiculous, and most people would object very strongly to the loss of privacy.

This does not mean that there aren't any negative feedback loops that could be made more accurate, because of course there are. But there are many more cases of systems which appear sloppy but are actually functioning in the most efficient way. In either case, the negative feedback loop leaves its "signature" in the pattern of change/response/change/response...over and over again. Any time you spot this kind of cyclical or zig-zag behavior in a system, you can be almost sure that there is a negative feedback loop behind it.



TYPICAL FEEDBACK "TRACE"

Reaction Times: Every negative feedback loop also has certain time limits which affect its behavior. One of the most important of these is the "reaction time," which is the minimum amount of time necessary for one complete circuit around the loop. Suppose, for example, someone sticks a pin in your arm. The reaction time, in this case, would be however long it takes for the pain to register, for the reaction signal to reach your muscles, and for the muscles to move your arm away from the pin.



The reaction time for a simple pain reflex is quite short, taking only a few tenths of a second. Something more complicated and less urgent--like reacting to a street sign--takes longer because it requires conscious thought Some mechanical systems, particularly electronic ones, have very quick reaction times, but others are quite slow. The basic thermostat/furnace cycle, for example, takes quite a while, because of the slow rate at which the air carries heat from the furnace to the thermostat. And social systems, in general, tend to have long reaction times. A company may take weeks or months to react to changes in buying patterns, while the political process often takes

months or years to react to a change in the political situation.

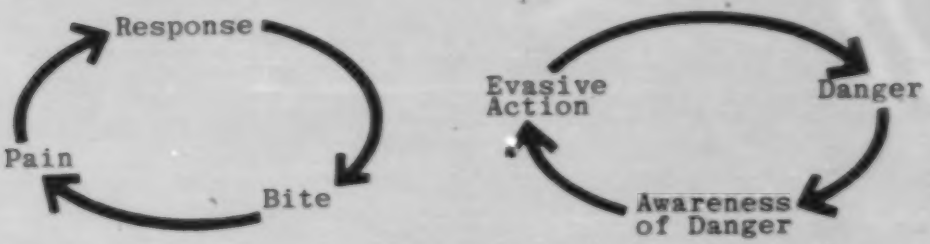
Reaction time is important. If it is too slow, change can occur so fast that the system is damaged before it has a chance to respond. In addition, the reaction time is usually the same as the basic tempo or "beat" of a system--the minimum interval between the "wobbles" of the feedback cycle. So, by watching these wobbles and estimating that interval, you can frequently find out the minimum time period (and thus the fastest change) which a particular system can cope with.

Anticipation: Sometimes a system can't afford the delay that even a fast-reacting feedback loop involves. If the problem is a mosquito, you can ignore it until you feel it start to bite, and then react to it. (Smack!) But if the problem is a man-eating tiger, you had better find some way to respond

"Systems cope with problems by reacting to warnings"

before it bites, or even the fastest reaction time won't save you!

Systems cope with problems like this by reacting to warnings--events that usually happen before a particular problem occurs. Before a tiger attacks, you will usually see it, hear it, or smell it and have a chance to run or hide. This is still a negative feedback loop, and your reaction time is still important, but the loop is based on the warning signal rather than the actual problem:



The reaction time in the first loop has three parts: the time it takes the pain signal to travel up the nerves after the bite starts, the time it takes to choose and send a response signal, and the time it takes to swat the mosquito and stop the bite. The reaction time in the second loop also has three parts--from the start of the danger to an awareness of it, from awareness to the decision on how to respond, and from the decision to the end of the action that eliminates the danger--but the first part has become much more important. It helps if you can think fast and run fast, but that won't do you any good if your senses

don't warn you of the danger in time.

Being able to anticipate dangers depends for most animals on sight, smell, hearing, and the ability to interpret the information from these senses. These traits are so useful for avoiding danger, as well as for finding food and mates, that evolution (see Chapter 7) has selected steadily for better and better senses and brains. (Of the two, better brains are somewhat more important than better senses: it does no good to have super-sharp ears if you can't tell that a tiger's cough means danger.)

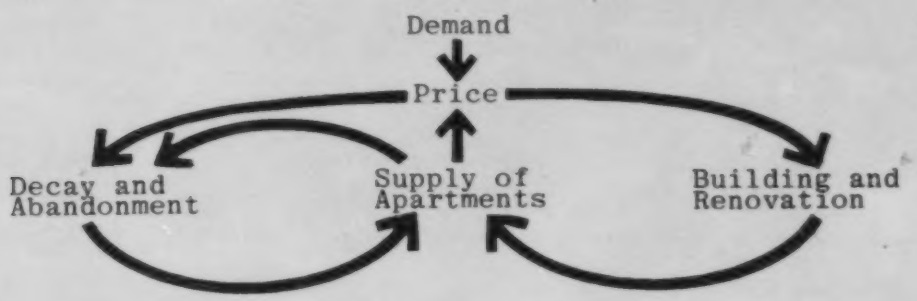
The same process can also be used to improve the stability of social systems. If a country waits until it is attacked before it mobilizes its defenses, it is in bad trouble. If it regularly collects information about other countries, however, it can prepare its defenses in response to the warning that another country is getting ready to attack. If farmers wait for the fall rains to begin before they start to harvest, most of their crops will be ruined. But if they respond instead to a forecast of bad weather ahead, they can get their crops in before the rain starts. Similarly, if slide-rule makers wait until they are fired to start learning a new trade, they will likely have a difficult time. But if they see that pocket calculators are going to wipe out the slide-rule market, they can start looking around for a new trade while they still have plenty of time left to make the change.

To look at it from another point of view, one reason many systems have inadequate reaction times is that they have negative feedback loops which respond to problems rather than adequate warnings of those problems. This is especially true of political systems, particularly (as we will see in chapter 10) when the political system intervenes in the economic and ecological systems. The failure to build more effective provisions for foresight into our social systems is in many ways the most dangerous and most serious limit we face.

"Counter-Intuitive" Systems: Negative feedback often produces behavior which appears contrary to common sense, or "counter-intuitive." We saw one example of this in the predator-prey relationship, where killing the deer's enemy (the wolf) was actually harmful to the deer. A similar situation occurs when a farmer tries to kill off a pest. Most insect pests have predators which keep them under control naturally. Unfortunately, most pesticides kill the predators as well as the pests. Since the pests usually breed faster than the predators, this means that the next generation of pests will arrive and there will be no predators there to control them. The result is a pest "explosion," and the farmer is worse off than he was when he started.

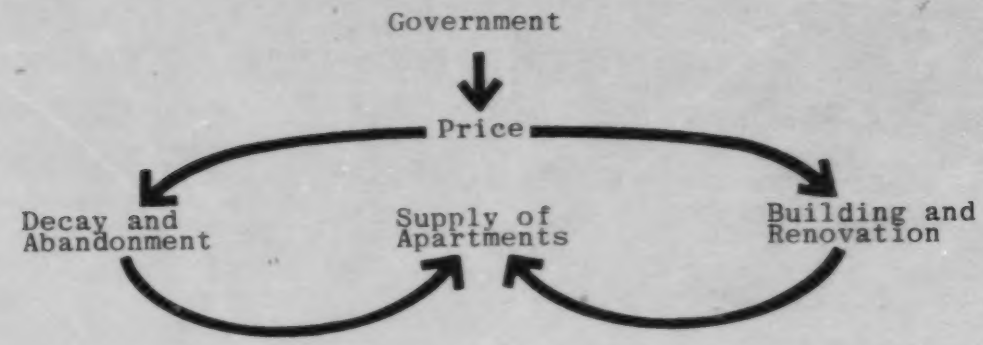
There are many other situations where a solution to a

problem seems "obvious," but either doesn't work or actually does harm because of the way the system tries to cancel out the interference. For instance, most of us take for granted that there will be enough housing for us to find shelter, though we may pay more for it than we wish. But suppose that many people decided at the same time to move to a particular city. Suddenly, there will be many extra people looking for places to live and not enough houses and apartments to go around. Landlords will find that they can raise rents and still rent all their units. This makes apartment buildings more profitable, so people rush to build new ones and fix old ones up instead of letting them fall apart. For a short while, rents are high, which is unpleasant, but this leads to an increase in the supply, which solves the basic shortage and helps bring rents down again.



However, in some cities, the people looked at only the short-term problem--high rents--and demanded that government "do something." So the government did the "obvious" thing and passed laws limiting the rents

landlords could charge. This, they thought, would surely lower the price of housing.



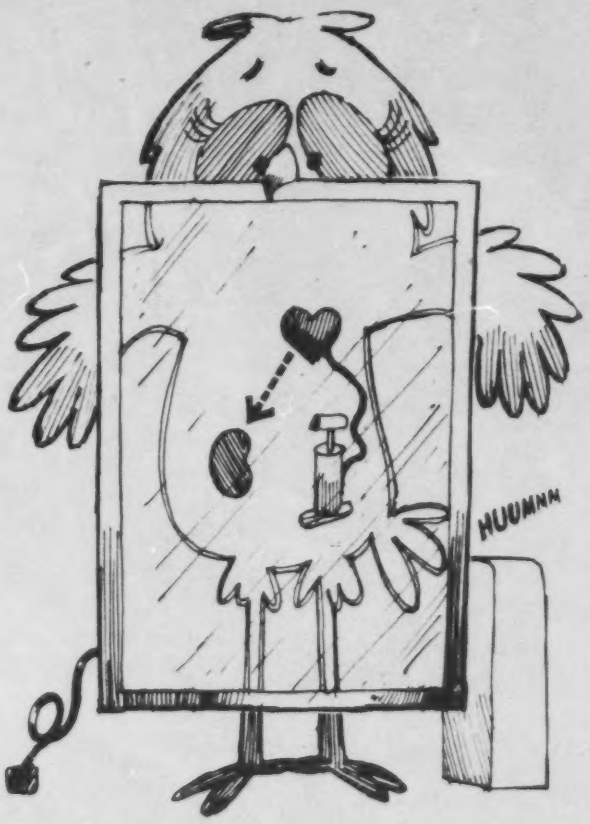
In the short-run, the rent controls did make housing cheaper. However, landlords found that they could not charge more rent in order to keep buildings in repair, so they either let the buildings run down, or they sold them and moved their business elsewhere. Gradually, buildings decayed. Moreover, builders were not interested in constructing new housing units, because they were afraid that, with rent control, they could not make enough to pay back their investment and to make up for the risk they took in building large developments. As a result, although housing was decaying, less new housing was constructed. There were fewer and fewer apartments available, and the price of those not controlled began to rise because of the scarcity. Over the long run, the city with rent control found that it had less housing for its citizens--and that the housing was more expensive and of lower quality!

Here is another example. High blood pressure is a serious problem which affects millions of people. Normally,

blood pressure is controlled by a negative feedback loop which has an adjustable setting. When you are afraid, for instance, your body produces chemicals which raise the "target" of this "pressure-stat", just like increasing the temperature setting on a thermostat, and your blood pressure goes up accordingly. When you relax, the target is lowered again and your blood pressure drops back to a safer level.

Sometimes, however, the "pressure-stat" gets stuck at the higher setting for some reason, perhaps because a person is under too much stress or consumes too much salt or coffee or has something wrong with his body chemistry. When this happens, the problem can be solved by eliminating the cause and/or by taking drugs which push the "pressure-stat" setting back down again.

But it turns out that the body also has several other systems which affect blood pressure. One of these involves the kidneys, which filter waste products out of the blood. If enough blood isn't reaching your kidneys, these wastes build up in the blood and poison you. To keep that from happening, the body has a backup system



which raises the blood pressure whenever the blood flow to the kidneys drops too low.

Consider what happens if something partly blocks the arteries that carry blood to your kidneys. The effect is like putting a kink in a garden hose--the flow below the kink drops to a trickle. Your body reacts to this in the only way it can, by pushing the blood pressure setting higher and trying to force more blood past the blockage. Of course, this means that the blood pressure everywhere else goes up too, which causes other problems, but at least it keeps you alive.

Now see if you can figure out what will happen if you go to a doctor for help. Since the problem is high blood pressure, the "obvious" solution is to give you one of the drugs that reduce blood pressure. The medicine causes your blood pressure to drop, which reduces the flow to the kidneys, which makes your blood pressure go right back up again! If the doctor gives you a slightly stronger dose of the medicine, your body just fights back a bit harder. Pretty soon, if the doctor gets stubborn, you are caught in a tug-of-war between the drug and your kidneys--and if the drug wins, you die of blood poisoning! (For your sake, however, let's hope the doctor is enough of a systems thinker to find the real solution: surgery to remove the kink in the kidney arteries.)

Again, the pattern is the same: the "obvious" solution doesn't work because the negative feedback loop is set up to cancel out any direct interventions. In fact, as we have seen, the "obvious" solution often makes things worse. If you want to change a situation which is controlled by a negative feedback loop, it is much better to try to change the way the pieces interact than to try to "out-muscle" the system. But that means that you first have to figure out what the system is and how it works.

"The 'obvious' solution often makes things worse."

Hidden Systems: Even if you understand how negative feedback works, it is often hard to guess how a system will react to a change because the feedback loops you need to know about are seldom out in plain sight. For example, the villagers in one region of Africa had trouble with hippopotamuses coming up from the river to eat up the villager's gardens. But when they killed off the hippos, many

of the villagers got sick. Nobody could understand why, until a local scientist finally discovered the connection. The disease was caused by an organism which bred in the mud along the river. When the hippopotamuses churned up the mud, they killed most of the eggs and kept the organism under control. With the hippopotamuses gone, the organism could breed freely--with disastrous effects on the health of the villagers.

Another example--one that harmed hundreds of millions of people--occurred in the United States in 1929, when Congress decided to pass a set of heavy tariffs (or taxes) on products being brought into the United States. Investors began selling their shares in companies that depended--directly or indirectly--on imports or exports. This helped trigger the terrible stock market crash of that year. Yet no one at the time seems to have realized that there was a connection between the two events, even though the stories ran side-by-side on the front pages of many newspapers. If the tariff act really did trigger the crash, it might well have been one of the worst decisions in history, since the stock market crash led to the Great Depression, which helped Hitler come to power in Germany, which led directly to World War II! Hidden system-linkages--like this one connecting free trade to economic stability--are worth searching out, even if they are sometimes hard to find.

Vulnerable Systems: Even the most stubborn negative feedback system is usually vulnerable to things which interfere

with the way information is passed along in the feedback loop. For example, a breeze so weak that you would hardly notice it might still be able to knock you off your bicycle if it blew smoke or dust in your eyes. By making you shut your eyes, the breeze reduces the flow of information to your brain and easily disrupts the system, even though it doesn't have the strength to "out-muscle" the system. Similarly, nerve poisons are the deadliest kind because they attack the body's communication system. And any attempt to censor the press is dangerous to a democracy for essentially the same reason: it disrupts the flow of information which people need to make intelligent decisions.

However, sometimes this vulnerability can be used to good advantage when you <u>want</u> to change the way a system is acting. If obvious solutions don't work, it is often worthwhile to search for the negative feedback loops that are causing the trouble and try to find an indirect way to change their behavior.

For example, if you want to cool off an overheated house on a winter day the "obvious" solution is to open a window. But as soon as the temperature drops a few degrees below the thermostat setting, the furnace comes on full-blast, and all you do is waste a lot of energy. If it is cold enough outside, you might actually succeed in cooling the house this way--if you don't mind having the furnace on all the time--but it would be much more sensible to just change the setting on the thermostat.

However, suppose that for some reason you <u>can't</u> change the thermostat setting. You might decide instead to put a small heater --like a light bulb--right underneath the thermostat. The extra heat from this heater would "fool" the thermostat into thinking that the house is hotter than it really is, which would cause it to turn the furnace off, letting the house cool down. In other words, adding heat to the system (at the right point) can actually make it cooler! Sounds crazy, doesn't it?

"It would be more sensible to change the thermostat"

Now suppose you stuck an ice pack on the thermostat instead of putting a heater under it--what would happen? The thermostat would feel the cold air from the ice pack and "think" that the house was too cold. As a result, it would turn the furnace on, making the house even hotter. So adding heat can make the system cooler, and adding ice can make the system hotter! Crazier and crazier!

The farmer can use a similar approach to solve his

problems with pests eating his crops. When he tries to poison the pests, he also poisons their predators and ends up with a worse pest problem than ever. What would a "systems solution" to this problem be? One answer that a lot of people are experimenting with is to control the pests indirectly by increasing the number of predators. One way this can be done is to build bird houses for the kinds of birds which eat this particular type of pest. Another approach which some people use is to collect praying mantises and ladybugs and put them in their gardens or greenhouses. These two insects eat many of the other kinds of insects which do a lot of damage to vegetables and other plants.

Similar solutions show up in many other situations, and we will have a chance to look at some of these in later chapters. But by this point you should be getting an idea of why a systems approach to problems is so important. Without it, people who try to solve problems or improve things frequently pick a "solution" that doesn't work or that backfires by making the situation worse. Since their solution looks reasonable, and they can't understand why it won't work, they usually respond by trying even harder. Eventually, they get tired, frustrated, and angry, and they often end up deciding that the system itself is basically evil or that there is some kind of conspiracy to keep anybody from improving it.

System thinkers, on the other hand, realize from the beginning that all stable systems have, by definition, ways of resisting change. Instead of stubbornly fighting against the system, they study it carefully to find out where the negative feedback loops are, how they work, and where they are vulnerable. A system solution may be quite indirect and difficult for other people to understand, but it is more likely to work, and that is much more satisfying.

Chapter Four: CHANGE AND GROWTH

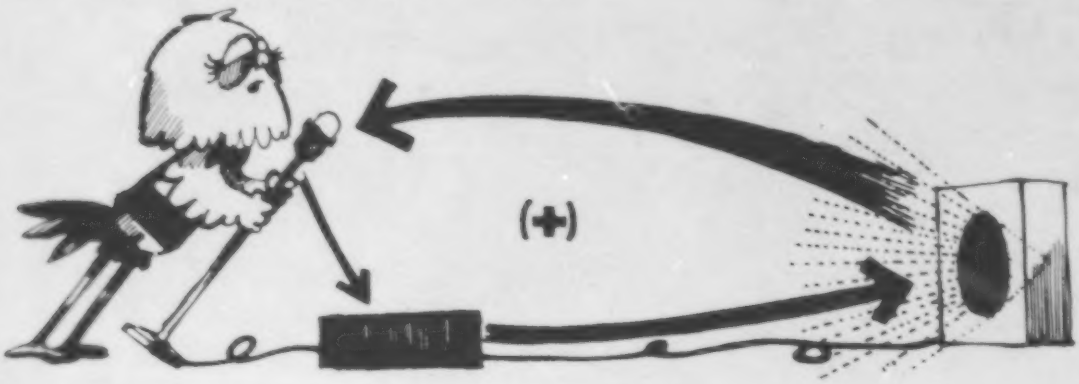
Negative feedback loops provide stability for the systems in our environment. How then do change and growth occur? Some change occurs when a negative feedback loop breaks down, such as when a person gets heatstroke or when a social system becomes unstable and collapses. Some change results from the feedback loops themselves, as they try to adapt to changes in other parts of their environment. And some of it clearly comes from chance events, such as a new mutation or the winning of a million dollar lottery, or the eruption of a volcano. But a great deal of change going on around us comes from a

completely different kind of feedback process, called positive feedback.

Feedback occurs when a change in one part of a system produces changes in the whole system which then "feed back" through the system and affect the original part again. Negative feedback works to cancel out, or negate, changes. The system "corrects" changes in its parts. When one part of the system gets "off target," the negative feedback loop provides adjustments to bring it back. But what happens if the feedback loop does just the opposite, and each change feeds back through the system to cause more change? The new change will cause still more changes, and so on, until something breaks the cycle. This is called "positive feedback" because it amplifies or adds to any disturbance in the system.

Have you ever been in a concert or lecture hall when the public address system suddenly let loose with an ear-splitting "S)UAAWWK"? This is caused by the accidental creation of a positive feedback loop. The microphone picks up sounds which it converts to an electrical signal. This signal is then multiplied in strength by the amplifier and used to drive a loudspeaker, which converts the signal back to sound again. The sound then spreads out again from the loudspeaker, losing strength as it goes. Some of this sound may reach the microphone. If this amplified sound is stronger when it hits the

microphone than the original sound which caused it, the microphone will send a still stronger signal to the amplifier. The amplifier will increase it more, and the loudspeaker will change it back into sound again. Then the new noise from the loudspeaker hits the microphone with still greater intensity. For each additional trip through the system, the noise is multiplied again until the loudspeaker is making as much noise as it possibly can. Each sound--fed back into the system--is a signal for the system to produce more.



Sound and electricity both move so quickly that a signal can travel around this positive feedback loop thousands of times in a second, picking up volume each time around. The noise seems to reach full volume almost instantly. Once it does, that "SQUAAWWK" would continue until someone intervened or the equipment broke down. To stop it, you have to break the feedback loop. You don't have to turn the amplifier down. You can just interrupt the feedback by muffling the microphone

with your hand, or by moving the microphone further away from the speaker. Anything that cuts down the sound reaching the microphone, so that it is less than on the previous cycle, lets the noise fade away.

Although it works much more slowly than a sound amplifier, a savings account functions like a "money amplifier," by means of a positive feedback loop. Suppose that you have $1000 to put in the bank, and the bank pays you 5% interest each year. Since 5% of $1000 is $50, at the end of the first year you will have your $1000, plus $50 more, for a total of $1050. If you leave this money in the bank for a second year, you will earn 5% of $1050, which is $52.50, and at the end of the year you will have $1050 + $52.50, or $1,102.50 The third year, the money will earn 5% of $1,102.50, or $55.13, for a total of $1,157.63. The table below shows how the interest grows, year after year.

YEAR	Interest Earned	Total in Account
1	$50	$1,050
2	52.50	1,102.50
3	55.13	1,157.63
4	57.88	1,215.51
5	60.77	1,276.28
6	63.81	1,340.09
7	67.00	1,407.10
8	70.36	1,477.46
9	73.87	1,551.33
10	77.57	1,628.89
11	81.44	1,710.34
12	85.52	1,795.86
13	89.79	1,885.65
14	94.28	1,979.93
15	99.00	2,078.93

As you can see, this process nearly doubles your money--from $1,000 to $2,000 in just 14 years. The money will double again in the next 14 years--from $2,000 to $4,000--and again for each 14 year period. The first time the interest is "fed back" around the loop, it adds only a small amount to the bank account. With each additional trip around the loop, a larger and larger amount is added. The positive feedback process amplifies the change.

An entire national economy can grow in this way. Farms, mines, factories, and businesses constantly create wealth, turning less valuable things into more valuable things. Instead of consuming all of the wealth they produce, people can invest some of it each year, using it to create more farms, mines, factories, and businesses, or to make the existing ones bigger or more efficient. Then even more wealth can be created the following year. Since more wealth is being produced, more can be invested. The additional investment makes it possible to create still more wealth, which lets people invest even more, and so on. Once again, positive feedback is at work--this time amplifying society's wealth.

Simple one-celled organisms, like bacteria, may be able to divide as often as every half hour under favorable conditions. If you start off with a single cell, it divides and becomes two separate cells. After half an hour, each of these cells divides, producing four new

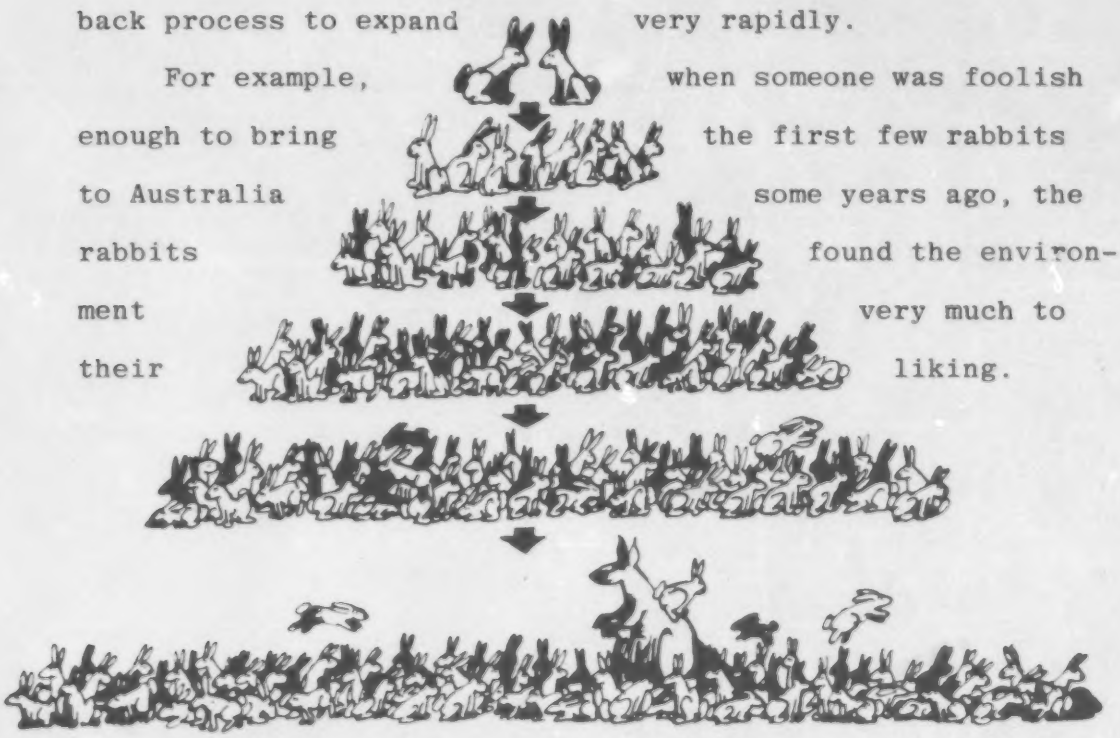
cells. After another half hour, these divide again to create eight cells, which divide again to make 16, and again to make 32, 64, 128, and so on, doubling the number every half hour. Believe it or not, you would have more than one million cells after only 10 hours, and in just one day there would be more than 280 trillion bacteria--all produced from that same original cell!

All living things use this system to grow. Like almost all animals (and plants), you started out as a single fertilized cell, which divide into two, divided again into four, and kept on dividing. Unlike bacteria, however, your cells clung together in a clump instead of going their separate ways. Soon the cells in different parts of the growing clump began to assume different roles, some of them becoming skin cells, some becoming muscle cells, and some becoming nerve cells. Fortunately, each cell is also pre-programmed to stop dividing when it reaches a certain condition. Otherwise you would have kept on growing faster and faster until it killed you. (This is what happens when people get cancer: some of their cells lose the "stop dividing" signal, allowing the positive feedback process to start up again. Cancer cells then keep doubling, and grow out of control until they choke or destroy some vital part of the body.)

When we look at the next higher level of living systems, we find that species grow the same way that individual cells

and organisms grow. Let's take rabbits for an example. Suppose we have a bunch of rabbits including ten adult females. (The exact number of males doesn't matter.) Let's assume, also, that each of these adult females has ten daughters who survive and grow up and are each able to produce ten more daughter rabbits. At this rate, there will be ten adult females in the first generation, one hundred in the second, one thousand in the third, ten thousand in the fourth, a hundred thousand in the fifth, and one million females in the sixth generation! Of course, conditions rarely allow this rate of growth to continue for even four or five generations, but when circumstances <u>do</u> permit it, the rabbit is able to use this positive feedback process to expand very rapidly.

For example, when someone was foolish enough to bring the first few rabbits to Australia some years ago, the rabbits found the environment very much to their liking.



"...and had spread to every corner of that large continent."

Within a decade or two, those few rabbits had become millions and had spread to every corner of that large continent....breeding like rabbits, indeed!

So far, we've looked at mechanical, economic, and biological systems which use positive feedback to amplify change. Are there any others? The answer is that there are many, many more examples of positive feedback that we could use. In fact, positive feedback loops are almost as common in the world around us as negative feedback loops are.

One of the positive loops that has had a big effect on the human race is the one controlling the growth of knowledge. Back in prehistoric times, knowledge accumulated very slowly. An individual learned some things about his environment by direct experience and learned other things from other members of his tribe. In his short life, he might learn a few new things worth passing on to others, like a new way to shape an axe or a better way to plant crops. But he had no way to measure precisely, no time to study things that didn't directly affect his survival, and no way to record what he learned. When he died, most of what he learned died with him. Knowledge could be stored only in the frail human memory.

If very knowledgeable people died before teaching what they knew to people around them, information was lost, and the next generation ended up knowing less about its

environment than its parents did. If everything went well, it might know more. In what must have been the normal situation, it usually ended up knowing just about the same amount, for old facts would be forgotten and new discoveries made. Over many thousands of years, the gains might outnumber the losses, but by a very small margin. An epidemic or famine could set knowledge back sharply at any time. So progress was painfully slow.

Gradually, however, enough knowledge accumulated that people could run their lives more efficiently. Inventions like fire, farming, and astronomy gave them protection from the world around them and a better food supply. The new knowledge brought changes that permitted still more knowledge to be sought. People had somewhat longer, calmer lives, so they could spend more time and effort learning about their world and passing their knowledge on to others. They preserved and enjoyed it in paintings and carvings in the huts and caves where they lived, and in tales and songs they performed and remembered.

Even so, the accumulation went on very slowly until the invention of writing, about 5,000 years ago. Here, finally, was a way for people to record their knowledge for future generations without having to pass it on by word of mouth. The advantages were enormous. No longer would information be unavoidably lost because someone died.

No longer was it necessary for an individual to spend time teaching the knowledge directly to everyone who wanted to learn it. No longer did discoveries have to be put in an artistic form to be remembered. Writing provided a permanent record which could be used by anyone who knew how to read.

Writing greatly speeded up the process of accumulating knowledge. The development of techniques for precise measurement and calculation, especially the development of arithmetic and geometry, also made the process move faster. Increased knowledge also allowed people to produce food and wealth more efficiently, which allowed more people to spend most of their time pursuing more knowledge.

Eventually, people discovered that they could learn more and learn faster if they went about learning in a systematic way, and they began to discover the best ways of doing this. The result is the process called science, which is really nothing but a set of guidelines for the most effective ways to investigate and understand the world around us. Some of its tools are logic, mathematics, statistics, and devices like microscopes and telescopes that let us see or measure things that we can't observe directly.

More important in the development of science, though, was a set of beliefs. Scientists believe that knowledge

can be accumulated faster if all scientists follow certain rules. Scientists are supposed to be absolutely honest about what they see, they should write down what they learn and distribute it to other scientists, and they should test their theories by actual experiments and not just rely on the opinions of authorities.

Of course, science didn't develop all at once, and many problems still hindered the accumulation of knowledge. For one thing, there were many, many mistaken beliefs which were mixed in with the facts that were being recorded and passed on. For another, copying documents by hand was a very slow and expensive process, so information moved slowly and was still often lost if just a few copies were destroyed. For example, the great library at Alexandria in ancient Egypt was destroyed by fire, along with all its contents. Many of the books and scrolls and records that it contained were the only copies anywhere in the world. As a result, we know of many important writings from ancient Greece, Rome, and Egypt only by references to them in other writings.

In the 16th century, however, Johann Gutenberg developed a fairly simple and inexpensive method for printing many copies of the same book. This allowed knowledge to accumulate faster. It became harder for information to be lost once it had been printed in many copies and distributed, and it became much easier for a student to get access to the knowledge that did exist.

The result of all these developments has been a continual acceleration of the rate at which knowledge has accumulated. At first, it was gathered very, very slowly. Then the pace began to pick up gradually until, with the development of printing and modern science, it has turned into a knowledge explosion. And it turns out that the more knowledge you have, the easier it is to create new knowledge. If you are trying to invent the airplane, it helps if other people in the society know how to make engines and fuel. If you want to figure out how to start a new kind of business, it helps a great deal if the local library has dozens of books on starting new businesses.

"At first, it was gathered very, very slowly. Then the pace began to pick up slowly until... it turned into a knowledge explosion."

Furthermore, the more knowledge you have, the better off your society is, and the more people it can support to spend their time looking for more knowledge. One figure that is widely quoted illustrates this very well: 90% of the scientists who have ever lived are alive and working today! In other words, even though you can't

touch knowledge, or see it, it can still grow by positive feedback in the same way that rabbits and businesses grow.

The only limit to positive feedback here is that we eventually come to a point where there is so much information that we can't find the information that we need. Fortunately modern computers may hold the key to coping with this information explosion, by organizing the knowledge we have and retrieving what we need at a particular time much faster than we can do it with books and magazines and file cabinets. But since computers are also a product of the growth of knowledge, this too is just a further extension of the positive feedback process.

Other important positive feedback loops can be less desirable, however. One of these is the positive feedback loop of power, which has created problems for people since before the beginning of civilization. A power growth loop works like this: when an individual (or group) gains power in a society through wealth, violence, religion, politics, or any other means, he has the ability to harm or help other people. Those other people naturally wish to please the person who has the power, so that they can avoid harm and share in the rewards. Now, the power-holder not only has the original source of power, he also has a group of people who are willing to do what he wishes, which gives him even more power to help or harm other people.

As a result, even more people will wish to please him by doing what he wants, which gives him still more power. If nothing is done to stop this process, the individual will eventually control the entire society. This, in fact, is what has happened throughout history when tyrants and dictators have taken control of societies.

"...even more people wish to please him, which gives him still more power."

Perhaps the best examples in this century have been Hitler's Germany, Stalin's Russia, and Mao's China.

Because power can accumulate so rapidly, any society which is trying to avoid a dictatorship must find ways to control and restrain this positive feedback loop. In fact, democracy as we know it today is a direct result of a series of inventions (like free elections and independent judges and civilian control of the military) which people have learned through painful experience are necessary for controlling this tendency for power to accumulate in one place.

SUMMARY:

The examples of positive feedback discussed in this

chapter were selected with a purpose. The growth of knowledge, the growth of population, the growth of economic wealth, and the growth of power are the greatest forces for change in modern life. The growth of knowledge, by enabling human beings to make their lives more secure, longer, and healthier, has helped feed the growth of population. The growth of wealth and the growth of knowledge are actually interdependent, for new knowledge--inventions and discoveries about the way the physical world works--has helped people put their money to work in ways never dreamed of before, and to produce wealth beyond the imagination of earlier peoples.

However, both wealth and knowledge can also contribute to power. Knowledge of physics and chemistry, and even the understanding of how human beings work, can all be used to give some people power over others--better weapons, better ways of manipulating people's minds. Together, the modern growth of power, wealth, knowledge, and population create an unprecedented situation of rapid and continuous change. One of the basic challenges of our times is finding ways to control this headlong change.

Positive feedback loops also affect our lives in less general ways. The spread of a fire, a rumor, a chain letter, or an epidemic disease--all of these are the result of positive feedback, as are all chemical and nuclear chain reactions. What they all have in common

"Positive feedback loops affect our lives... as the spread of an epidemic or a rumor."

is an explosive quality, whereby a tiny initial spark can quickly cause enormous results. They are also often dangerous. As a result positive feedback loops are usually kept under very tight control in both natural and social systems, as we will see in chapter five.

Reminder: "Negative feedback" loops negate change, creating stability. "Positive feedback" loops amplify or add to change. Don't get them confused with "bad feedback" and "good feedback," or with "criticism" and "praise." Both terms are widely misused, so you have to be careful. Just remember that whether feedback is considered positive or negative depends on what it does to changes in the system.

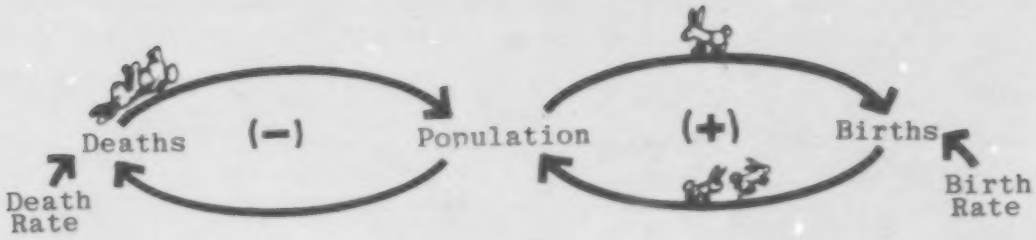
Chapter Five: PUTTING THE PIECES TOGETHER

Back at the beginning of this section, we discussed the origins of systems thinking. Originally, people thought that the best way to study a system was to find out what it was made of, so they studied these pieces. Gradually, they learned that it was just as important to understand how the pieces were organized, but they still thought that the organization of any one kind of system--such as a living thing, or an economy--was unique. Only in the last 50 years have people begun to realize that all complex systems have many things in common in the way they are organized, even though the "pieces" may be very, very different.

Plus and Minus: The organization of every complex system is built out of the same two simple elements that we have just been discussing: positive and negative feedback loops. If you can think of the atoms in your body as being the basic building-blocks of your body's physical content, for example, then positive and negative feedback loops make up the basic building-blocks of your body's organizational content. The same thing is true of all other kinds of systems.

This similarity gives us a powerful tool. Now that you understand the basic units of organization, you can hunt for them in any particular system and see the similarities between the way that system behaves and the way other systems behave. This means that you can apply your experiences with one system to another more easily, even if you have never encountered the other system before. It also means that once you understand how these basic building blocks go together in one case, you will be able to transfer that learning to other fields, instead of having to start all over again from nothing.

In this chapter, we are going to go a little further and examine the ways that different feedback loops can be linked together to build up more complex systems. Let's start with the simplest combination, using one feedback loop of each kind:

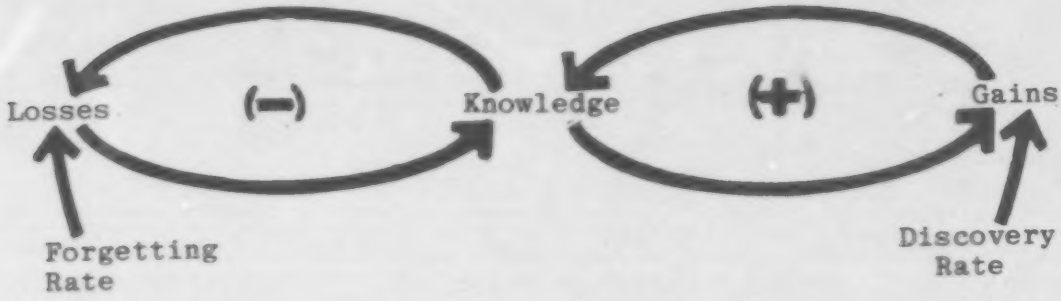


When we were talking about population growth in chapter four--whether of rabbits or people or bacteria--we were discussing the "plus" loop of this system: the more rabbits there are, for example, the more offspring they can have; the more new rabbits are born, the more rabbits there will be, and so on. On the other hand, as the population of rabbits increases, the number of rabbits that die each year also increases. This is the negative loop in the diagram above.

These two loops work against each other. If ten rabbits are born and six rabbits die, the population grows by four rabbits--the difference between the plus and minus loops. But if twelve rabbits die for every ten that are born, the population goes down. In other words, the actual behavior of the system depends upon which loop is "stronger." If the birth rate is higher, the population will grow; if the death rate is higher, the population will decline.

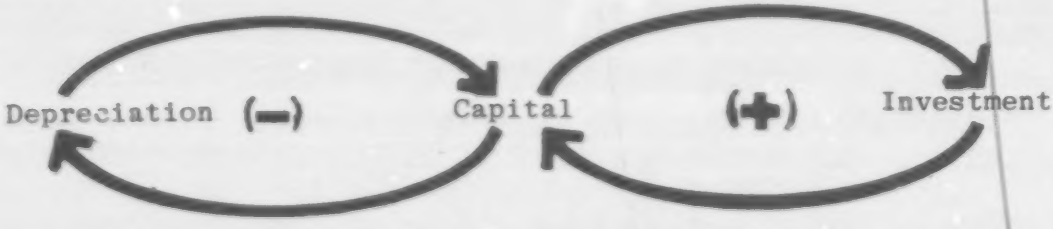
This isn't just limited to populations of rabbits, or people, or other living things. The same basic description applies to many other systems. For example, we saw that the growth of knowledge available to a society

depended on the difference between the learning rate and the "forgetting rate."

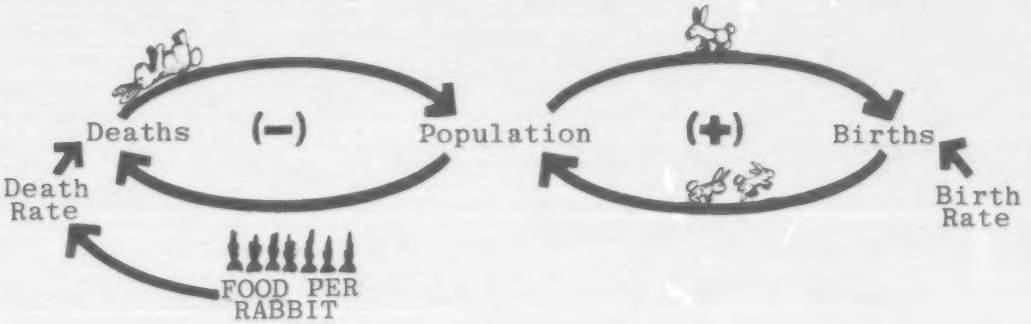


If more is learned than is forgotten, the supply of knowledge increases, and vice versa.

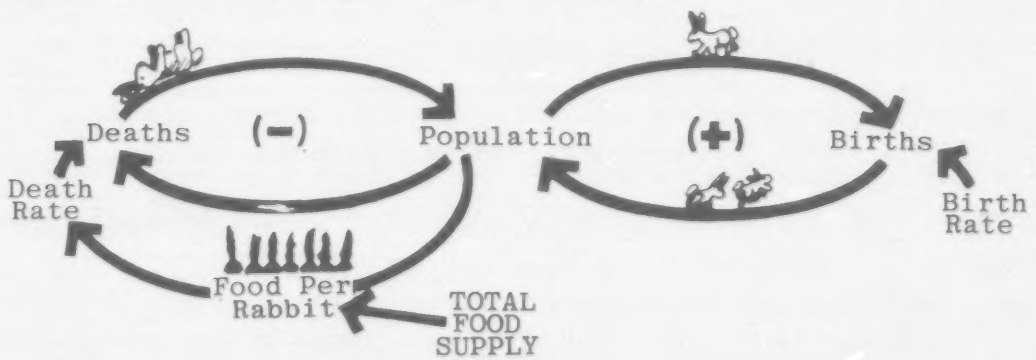
The same diagram can also be applied to economics. If a company takes in more money than it spends, it can grow, but if it spends more than it takes in, it will soon go broke. Another way of looking at the same thing, in terms of the whole society, is to think of our wealth producing capacity ("capital")--farms, mines, factories, and businesses--as a <u>population</u>. If machines wear out (depreciate) faster than replacements are being made (investment), the ability of the society to produce more wealth will decline. On the other hand, if more capital is being produced than is destroyed each year, the wealth of that society will increase.



Multiple Loops: The next logical step is to ask what controls the rate at which the basic positive and negative feedback loops work. Let's go back to our population diagram, using rabbits again, and add on some loops. The first thing we want to ask is, what kinds of things could affect the death rate for rabbits? One thing is obviously the food supply. If there is plenty of food for each rabbit, there will be lots of sleek, healthy rabbits who will live a long time. On the other hand, if there is not enough food to go around, some rabbits will starve and others will be weakened by hunger and will be more likely to die for other reasons.

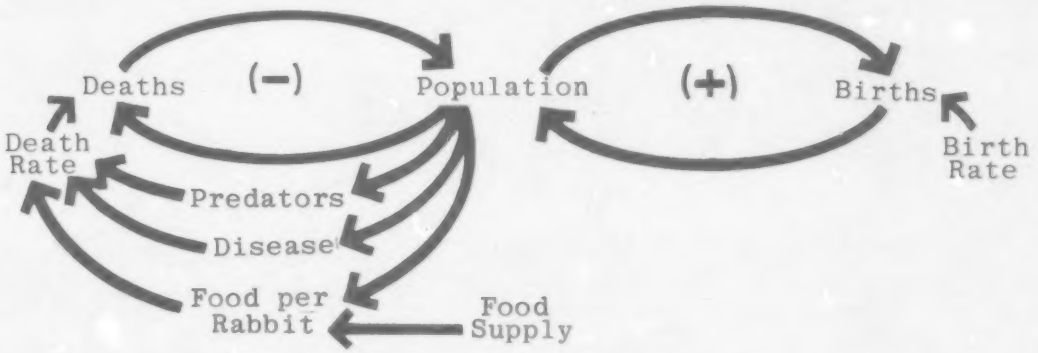


Now the two things that determine how much food there is per rabbit are the amount of food in a particular area and the number of rabbits in that particular area.



For the moment, let's assume that the amount of food is always the same. We now have an additional negative feedback loop: as the number of rabbits increases, the amount of food per rabbit decreases; as the amount of food per rabbit decreases, the death rate increases; and as the death rate increases, the number of rabbits goes back down again.

What are some of the other things that affect the death rate? Well, we've already talked about several possibilities back in Chapter 2, when we were talking about deer. Like deer, rabbits are affected by predators and disease. More rabbits means more predators, more predators means a higher death rate, and a higher death rate means fewer rabbits. Similarly, the more rabbits there are, the easier it is for a disease to spread rapidly and reduce the population. So let's add these two to our diagram.



Have we missed anything? Suppose the population grows so much that the rabbits are really crowded together. It turns out that too much crowding produces stress, that stress stimulates the adrenalin glands, and that if the adrenalin glands are stimulated for too long

the rabbits will just keel over and die from what the biologists call "shock." When they are in this condition, they will often go into convulsions and die at the slightest stimulus--a loud noise, the sight of an enemy, or even the appearance of a handsome rabbit of the opposite sex. In effect, they literally die of fright or excitment. So, if all of the other negative feedback loops--including food, predators, and disease--should fail, the ultimate negative feedback loop is an internal one, triggered by overcrowding.

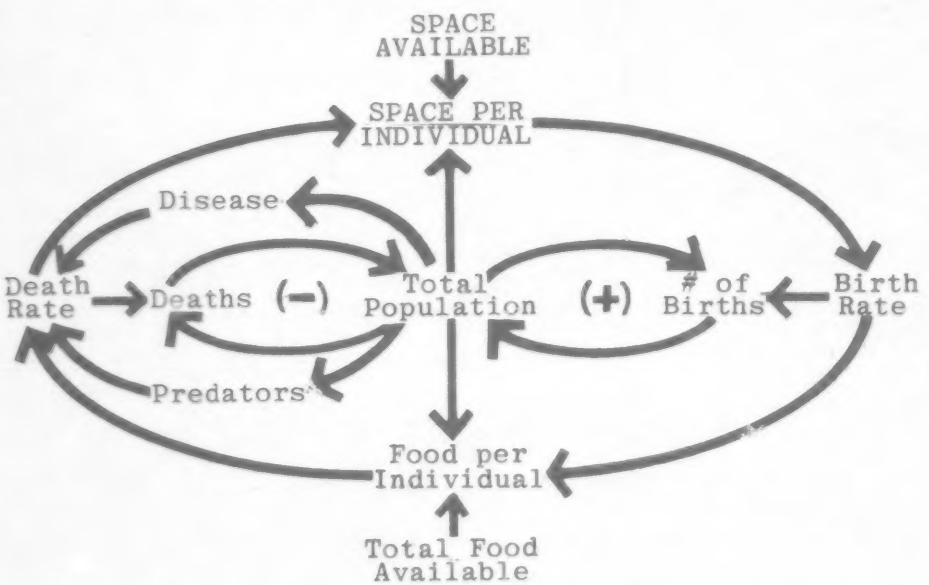
This last negative feedback loop is rarely used in nature because the others are so effective for most species. When it is used, however, the results can be spectacular. You have probably heard of the lemmings, small rodents in Scandinavia, which march into the sea and drown themselves by the millions approximately every four years. It turns out, after centuries of wrong guesses, that the real reason for this mass suicide is that the lemmings are driven crazy by periodic over-population and crowding. The snowshoe hares in northern North America also have a four year "boom/bust" cycle for the same reason.

Other animals use the amount of food or space available to control their population, but many do it by controlling the birth rate, instead of the death rate. For example, many types of birds will only mate, build nests, and lay eggs if they have a nesting space or territory of their own of at least a certain size. This doesn't affect the birth rate, as long as there is enough room for everybody, but

when the population gets high enough so that the territories fill up all of the available space, then the left-over individuals--those without territories--will not produce any young.

This same tactic is used by a wide variety of other animals, including wolves, lions, and many other hunting animals. It is also the basic way in which plant populations are controlled. For instance, if trees in a particular area are thinly scattered, new seedlings have plenty of room and can get plenty of sunlight to grow. As they fill up the area, however, each tree blocks out the sun from the area around it until there is no more space for a new tree to get started.

So now we have additional feedback loops which affect both the birth rate and the death rate:



(All loops are negative, except the "Total Population/# of Births" loop.)

The one that will eventually halt the growth of the population depends upon the particular situation. Sometimes these negative feedback loops work together to control the positive feedback loop. More often, a few do the main job, and the rest are kept in reserve for the times when the few "normal" controls are not strong enough.

This pattern is common in many types of systems, and often leads to frustration for people who are unfamiliar with the way systems normally behave. As we will see in later chapters in Section II, people often intervene in a system to eliminate a negative feedback loop that they don't like, only to be surprised when a worse one takes its place. For example, if disease is reduced through better medicine and nothing is done to limit the birth rate, the human population then increases to the point where there is not enough food and a great famine occurs, killing even more people.

We've spent some time on this discussion of ways that a variety of negative feedback loops can limit the growth produced by a positive feedback loop because this is a very common combination in the world around us. Positive feedback is so powerful that it can produce incredible amounts of growth in a fairly short period of time. Many complex systems use this potential for rapid growth to allow them to react quickly to changes in the environment. At the same time, if it is allowed to go too far, it is almost always

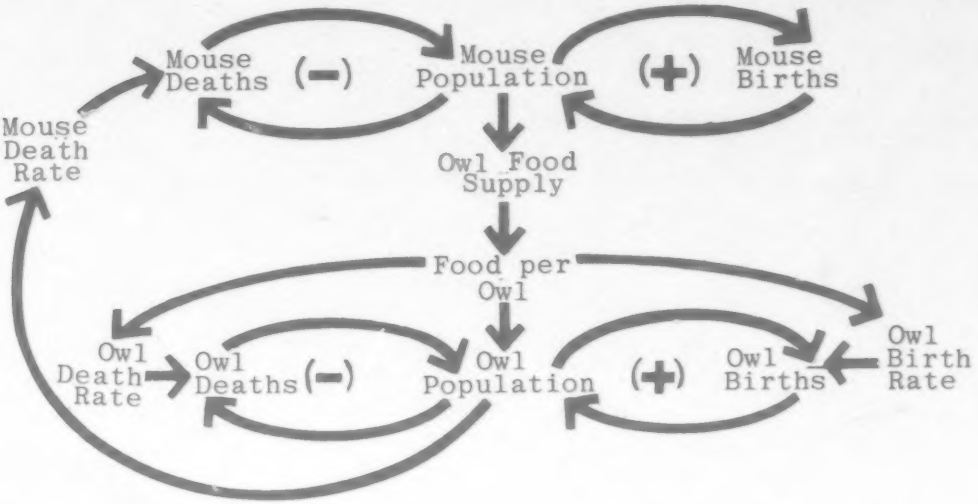
destructive and there will always be a limit somewhere, if only because of the fantastic numbers involved. (Remember the rabbits in Australia!) Most systems have therefore developed ways of stopping positive feedback after it has done its useful work, but before it reaches destructive levels. So one of the first things to look for in any complex system is the nature of the positive and negative feedback loops and the relationship between them. Generally speaking, the point at which the positive forces and the negative forces balance each other is the point the system will go back to, time after time, after being disturbed by some change in its environment.

This process of identifying the positive and negative loops is also important because it allows you to distinguish between things which are going to affect the system only temporarily, and things which are going to have a lasting effect. Essentially, any change--no matter how big--which does not change the important positive and negative loops, will be only temporary. At the same time, any change--no matter how indirect or small it seems--which affects the relationship between the plus and the minus loops is going to alter the long-term behavior of the system.

Competition: The examples above deal with combinations of many negative feedback loops, but only one positive one. What happens when a system has more than one positive loop?

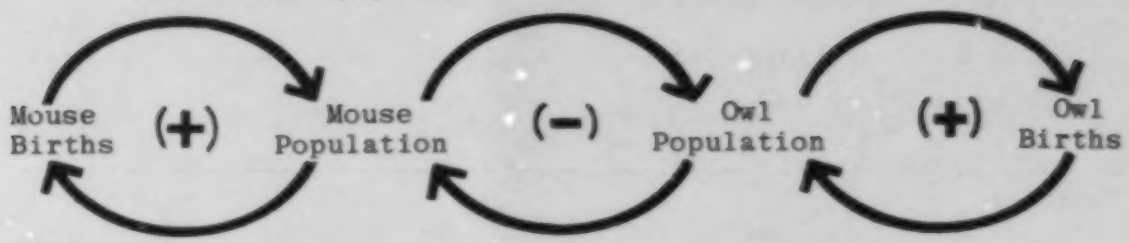
Actually, the population diagram on page 5.8 has two additional positive loops hidden in it: both the predators and the disease organisms increase by positive feedback whenever the rabbit population increases. From their point of view, an increase in the rabbit population means an increase in the available food supply, which relaxes one of the negative feedback loops restraining their own growth.

Here's a diagram of how this works, using field mice and owls for our example this time:



Positive feedback <u>increases</u> the field mouse population, which increases the owl food supply, which increases the food per owl, which reduces the owl death rate and increases the owl birthrate, which allows the owl population to grow, which increases the mouse death rate, which <u>reduces</u> the mouse population, which reduces the owl food supply, which increases the owl death rate and reduces the owl birthrate, which reduces the owl population, which..... etc., etc., etc.!

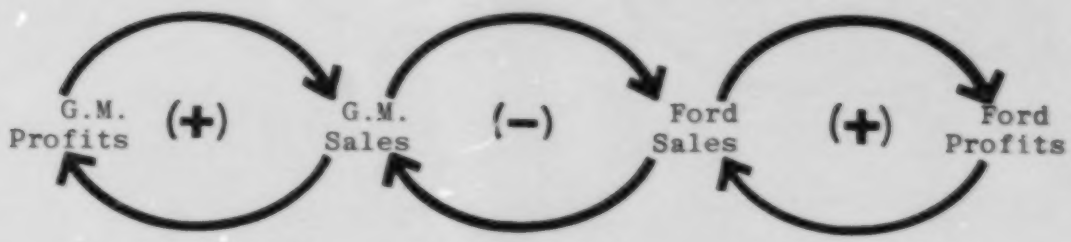
Or, more simply:



In other words, two positive feedback loops in competition with each other can provide stabilizing negative feedback for each other!

Competition is an important part of system design. Not only do predators and prey compete with each other for survival, but different predators also compete for the same prey. Foxes and owls for instance compete for food; more foxes means less food for owls and vice versa--and so on, with many competitors at each level, so that each helps control the population of the others.

In economics, companies limit each other by competition:



...and so on, for Chrysler, American Motors, Datsun, Toyota, Mercedes, Volkswagon (Rabbits again!), and all the others. Each company limits the other companies in two different ways: by actually taking sales away from the others and by forcing the others to keep prices down to keep from losing even more sales.

In politics, as we will see in Chapter 9, the competition is for power, competition between politicians, between political parties, between tne branches of the government, and between the levels of the government. If one politician does a bad job of representing the people, his opponent will try to gain power by telling the people about it. If members of the party in power try to steal an election, the other party will be right there watching them, hoping to gain power by catching them at it. If Congress gets out of line, the President can veto its bills, and so on.

Knowledge is also managed in this way. Scientists and scholars compete for status and respect by trying to make new discoveries and develop new theories. If one scientist already has a good deal of prestige--perhaps he has won a Nobel prize--people will tend to accept what he says, even if it is wrong, which gives him still more power and prestige. But scientists also get respect for discovering errors and disproving theories produced by other scientists. The result is that each scientist's efforts to increase his own prestige act as a check on the others' efforts. In the process, bad theories and false discoveries are weeded out, while good ones are encouraged.

A lot has been said in criticism of competition, and there is no doubt that it can be harmful if taken to extreme lengths. Owls instinctively

want to catch all the mice they can, but if they actually succeeded in catching all the mice in a region they would soon be much worse off as a result, along with all of the other mouse predators. Society benefits a great deal from the competition between political parties as long as they fight fair, but the public would lose those benefits if one party decided to seize power illegally, or even if one party was so successful that it completely wiped out its competitors in fair elections. Similarly, business competition encourages innovation and helps keep prices down, but if one company is so successful that it drives all its competitors out of a particular field then that company can raise its prices as much as it wants.

In other words, the kind of competition which one side completely "wins" is dangerous because it means ending the competition. However, real life is not a game, with a scoreboard, clock, and final score. As a result, natural and social systems generally balance sub-systems against each other in such a way that each will limit the others without winning a final victory that ends the competition.

This balancing process is dangerous, of course, since there is always a risk that a positive feedback loop will "break loose" and wreck the system. But positive

feedback is so useful when rapid growth is needed, that the risk is worth taking and all stable complex systems include growth loops surrounded by negative feedback loops to keep them under control. And since competition from other growth loops is the most effective form of control, most systems rely heavily on competition to keep things from blowing up.

The result of all this is a characteristic pattern that occurs in all but the simplest systems: a few powerful growth (+) loops balanced against each other and surrounded by swarms of stabilizing (-) loops which help keep them in balance. These two basic "pieces"--positive and negative feedback loops--can be put together in nearly an infinite number of ways, but the systems they make up have to follow this general pattern in order to survive. This is why successful systems, particularly complex systems, have the basic similarity of behavior which we will be discussing in chapter six.

Chapter Six: COMPLEX SYSTEMS

Although many of the systems we have considered so far are, like the human body, obviously extremely complicated, we have treated them as though they were simple systems, or parts of simple systems. That is, we have considered them as elementary units in systems with only one or a few feedback loops. This does not necessarily mean we have over-simplified our descriptions of the systems we have considered. Even complicated systems, like nations, are sometimes parts of fairly simple systems composed of other nations, even though each of the parts is itself a very complicated system. Indeed, as you have probably realized already, components of systems in the

real world are in fact members of thousands of larger systems, some of them simple, some not. Here we are going to consider some of the characteristics of what we will call complex systems, how they behave in ways different from simple systems, and some of the problems they present.

1. Self-Stabilizing systems: The first characteristic of complex systems is that they can keep themselves stable in the face of a wide variety of environmental changes. To do this, complex systems need to contain great numbers of negative feedback loops and they need to be able to get and use a great deal of "information" about their environments. The very simplest systems--like a thermostat with a fixed temperature setting--have only one loop and need only one piece of information (like the room temperature) to do their jobs, but they can handle only one kind of change. The thermostat handles a cold night automatically, but there's not much it can do about burglars or broken windows. Complex systems often contain thousands, even millions, of simple feedback loops so that they can "keep their balance" in spite of the many different kinds of changes that can happen in the real world.

2. Goal-seeking: Another characteristic of complex systems is that they appear purposeful. That is, in addition to responding to their environments, they appear

to have goals and to pursue those goals actively. In addition to surviving, living things "want" to produce offspring. Ecologies "want" to use every possible source of energy in the physical environment. Human beings want things like friendship, respect, security, and entertainment. Companies want to produce products and earn profits. It sounds perfectly all right when we talk this way about people, or social systems where the goals are chosen by people, but a little strange when we are talking about crabgrass "wanting" to produce more crabgrass. Nevertheless, non-human systems often act so persistent and ingenious about pursuing their "goals" that they seem to have minds of their own. Even human systems can appear to have their own goals, as when the economy "wants" rents to rise in a tight housing market, in spite of the fact that nearly all of the people in the economy want the rents to stay down.

3. Program-following: A third characteristic of complex systems is the ability to follow a "program" or sequence of steps, performing first one function, then another, then another, using feedback to decide when each step is completed. Cooking recipes provide a simple example: the cook is told to beat until fluffy, or bake until brown. When the egg whites are fluffy, or the cake is brown, the feedback loop is closed as the cook turns off the egg beater or oven and goes on to the next step.

A more complex type of program-following behavior is

one that includes branching. Branching programs are used for decision-making in many ways, from medicine to auto repair, and they can be exceedingly simple or so complicated that a computer must be used to follow the steps. The forks in the path, where choices between two or more options are present, are what distinguish branching from simple program following. The doctor examining a patient may look first for fever. If there is a fever, he looks for a sore throat. If a sore throat is present, he might take a throat culture to find out what is causing the infection. If there is no fever, or no sore throat, he will follow up alternate lines of investigation until he finds the probable cause of the illness.

"...The forks in the path, where choices between two or more options are present"

4. Self-reprogramming: As systems become more complex, they generally acquire both the ability to follow more complex programs and the ability to modify those programs so as not to repeat errors. Bake until brown is a program a cook might follow once: one bitter experience may modify the program to "bake until brown, but not dark brown." A mouse may go down a lot of blind alleys while searching for cheese in a maze; after several trials, however, it will modify its search program and go directly to the cheese with few wrong turns. If a football play fails repeatedly, a smart coach will drop it from his program for the game.

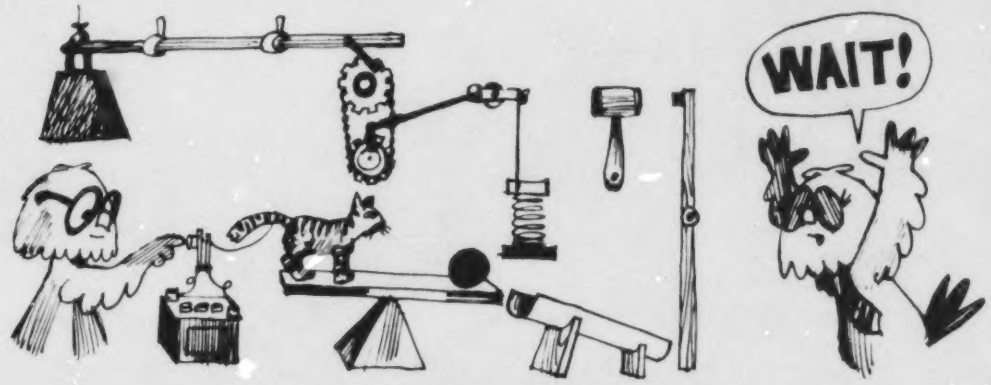
Reprogramming to avoid repeating errors is one of the most basic forms of learning. Even a cockroach can do it to some extent. At the next level up, however, reprogramming means inventing new, better ways to achieve the old goal, and it begins to require a degree of insight and creativity. The football coach, for example, uses more complicated skills when he invents a new play that works than when he simply drops a play that fails.

5. Anticipation: This characteristic of complex systems, the ability to anticipate changes in the environment, was discussed at some length in chapter three. Anticipation is sometimes "wired into" the system, just as a fly is programmed to take off whenever something a certain size approaches at a certain speed, without having to be taught

that such events mean danger.

In other cases, a system may learn by experience that one event usually precedes another one, and begin reacting to the first event in the way it reacts to the second. For example, if you ring a bell one minute before each time you feed your dog, the dog will learn to associate the two. Soon, it will start to salivate--that is, its mouth will literally start to water--whenever it hears the bell, even if there is no food around. Similarly, if a light flashes just before each time a rat is shocked, the rat will soon start jumping to safety whenever the light comes on.

Finally, anticipation--like reprogramming--can be the result of insight, as when we figure out how some system is going to act in a particular situation even



"...as when we figure out how some system is going to act even though we have never experienced that combination before."

though we have never experienced that combination before. Have you ever heard a joke or seen a movie and been certain that a person you know would particularly like or dislike it? To do that fairly accurately, you have to have a pretty good model in your mind of how the person's "personality-system" works, and then be able to put the model and the situation together and watch the result in your imagination. The same kind of thing happens when an engineer looks at a drawing and visualizes how a machine will work, or a politician looks at a proposed new law and tries to guess what the public's reaction will be. Each requires a degree of insight into the new situation in order to anticipate the response.

6. Environment Modifying: As we have seen, systems can improve the efficiency with which they interact with their environment by modifying the programs they follow and by learning to anticipate changes. There is an alternative approach, however: they can modify the environment to make it easier to deal with. All systems have some effect on their environments, of course, but it is usually an accidental effect, and often even a harmful one. If cattle and sheep eat the grass in an area right down to the roots, turning grassland into desert, they are altering their environment, but in a way that is not good for cattle and sheep. On the other hand, when beavers are unable to find a suitable pond, they will build a dam

across a stream and create a pond which they can live in, thus improving the environment from their own point of view.

Although many insects, birds, and other animals have programs for improving their environments, most of these are fairly simple path-making or nest-building programs. However, one animal--homo sapiens--has made a very successful specialty out of modifying its environment for a wide range of purposes. Farming alone has involved the physical remodeling of almost a quarter of the earth's land surface. Other activities, like mining, tree cutting, and the construction of things like buildings, roads, and airports, have also created enormous changes in both the physical and biological environment. These changes have often been harmful, as when plowing turns a prairie into a dust-bowl, or when tree cutting causes floods and landslides, but in general this human pattern of changing the environment to suit our needs is what has made civilization possible.

7. Self-Replicating: Another characteristic of many complex systems is the ability of the systems to reproduce, or replicate, themselves. The most familiar examples of self-replicating systems are living organisms which, through division or coupling with another organism, are able to produce copies of themselves. The process is so complex that it may never be fully analyzed, for it requires packing an incredible amount of program information into the nucleus

of each reproductive cell. These instructions must specify exactly how and when to combine a few dozen chemical elements, such as carbon, hydrogen, oxygen, nitrogen, and calcium, into skin or bark; wood, bone, shell, horn or teeth; hemoglobin or chlorophyll; blood or sap; milk, mucus, sweat, or venom; tendons, muscle, or cartilage; and all of the other substances that make up a living thing.

Although biological reproduction is the most obvious example, self-replication can also occur among social systems, such as when a society sends out pioneers to found a new community, or the owner of one McDonald's franchise creates another one. An interesting thing to note in both cases, biological reproduction and the founding of new institutions, is that the child is rarely an exact duplicate of the parent. Apparently systems which can replicate themselves are also complex enough to modify their programs slightly in the process. As we will see in the next section, this flexibility can provide a big survival advantage.

8. Self-Maintaining and Repairing: Another form of systems behavior typical in biological and social systems and rare in machines is self-maintenance and repair. Like self-replication, self-maintenance requires a huge library of information packed in a small space, and the result is rarely more than a very close approximation of the original. For example, the cells in your body are constantly dying and being replaced by new cells. Even though this means that the

system is constantly changing at the microscopic level, it also maintains the system as a whole and keeps it functioning. Similarly, if you cut yourself or break a bone, your body will try to repair the damage. If all goes well, the arrangement of cells when the healing is complete will be "close enough" to the original, but never precisely the same.

Social organizations also reveal this kind of behavior. In a city, for example, older buildings are constantly being torn down and new, different ones built to replace them. Even though, in one particular spot, a bowling alley might be torn down and replaced by an apartment building, the city as a whole will maintain approximately the same mixture of places for working, living, and recreation. And when a tornado or earthquake or other disaster destroys part of a town, the community will usually re-build itself in similar--but not identical --ways.

9. Self-Reorganizing: In addition to being able to maintain and repair themselves, some complex systems are capable of reorganizing themselves--actually rearranging their own parts and changing the connections between those parts--to meet new conditions or achieve new goals. This is easiest to see in social organizations, like a country that changes its form of government or a company that completely reorganizes the way it does business. However, many types of living systems are also capable of

"It's easiest to see in social organizations like a country that changes its form of government."

reorganizing themselves, even if not to the same extent. You can't grow gills or a tail, for example, but you can grow larger muscles, a larger heart, bigger lung capacity, and so on, in response to regular physical exercise.

In addition, the human mind has the very important ability to reorganize itself and its contents to a considerable extent. Most of us have had the experience, for example, of having bits of information that we've known for a while suddenly fit together to create a new picture of a situation. As we get older, we are constantly rearranging our memories in more efficient patterns, and even reorganizing our whole personality system. When this happens slowly, we call it "maturing," but it sometimes happens very rapidly, as the result of some personal crisis. A religious conversion, like the one experienced by Saul of Tarsus as described in the Christian Bible, is an example.

10. Self-Programming: Highly complex systems go beyond the beaver's simple selection among alternatives: to build or not to build a dam. They often appear to invent goals, not merely choose them according to some inherited program. A political system may pursue liberty over security, or justice over creativity, or honor over safety, or vice versa in each case. An economic system may choose opportunity over order, or predictability over fun. (Compare the Spartans and the Athenians, or the Puritans and the Polynesians.) They may do so without the conscious realization that those are the choices they are making.

After a new goal is invented, a new program must also be developed to achieve it, not always on the basis of pre-existing programs, but often on the basis of insight. This is typical of human activity when a new project, never before undertaken, is successfully pursued. There are no lessons of experience to follow; the program must be modified by insight. The Apollo moon landing is a conspicuous example.

These traits--the ability to invent new goals and the ability to devise new programs for achieving those goals--represent the highest level of flexibility in complex systems. Animals may demonstrate considerable ingenuity in solving problems, but the goals they pursue are essentially built-in, dictated by their genes. It could not occur to a wren to want to build cathedrals or to a pig to want to understand physics.

Both goals can, however, occur to human beings and to human social systems, as well as many other goals which go far beyond the purely genetic coding. In this respect, human systems are both more open and more unpredictable than non-human systems.

Problems of Complexity

We can summarize what we have discussed so far by saying that highly complex systems are: self-stabilizing, goal-seeking, program following, self-reprogramming, anticipating, environment-modifying, self-replicating, self-maintaining and repairing, self-reorganizing, and self-programming. These characteristics are listed approximately in order of increasing complexity, although a particular system may have one characteristic and lack another that precedes it. For instance, it would be much narder to build an automatic machine that is capable of reproducing itself than to build one that is capable of modifying its environment in a useful way, yet all living things do the harder task--reproduction--and many of them are unable to do the easier one. In general, however, the more complex a system is, the more likely it is to have most or all of the characteristics on this list.

Increasing complexity creates some advantages and some disadvantages. Compared with simpler systems, a highly complex system will normally be able to process more information, anticipate changes in the environment

more accurately, learn more quickly, act more flexibly, and in general be able to respond more appropriately to a wider range of changing circumstances.

On the other hand, more complexity also means that the system has more subsystems to maintain and coordinate, there are more places for things to go wrong, and more energy and resources have to be spent on information gathering and processing. Every increase in complexity has a cost, and useless complications just decrease the efficiency of the whole system. In spite of this, most of the complexity in the systems around us is worthwhile, because it adds more stability and efficiency than it takes away. It nevertheless creates certain kinds of problems which we need to be aware of when we try to deal with these systems.

The Tragedy of the Commons: The first of these problems is that complex systems have to contain many subsystems and these subsystems may have goals which conflict with each other or are harmful to the bigger system. One of the best illustrations of this is a situation known as "the Tragedy of the Commons," after an essay of that name by ecologist Garrett Hardin.

Hardin used for the scene of his illustration the "commons," or common pasture of medieval England and colonial America. "Common" in this sense meant that all

members of the community were entitled to graze their livestock there. The positive feedback loop involved in the use of the commons from the point of view of the individual livestock owner, goes like this: "The more cows I have, the better off I will be. Feeding them is free, so I will increase the size of my herd as fast as I can."

But this creates a situation which each individual is powerless to avoid. As each person increases his herd, the number of cows grazing on the commons increases; after a certain point, there are enough cattle to eat the grass faster than it can grow back; when there is no more long grass left, the cows will then crop the remaining grass right down to the ground, killing the plants and leaving nothing but bare dirt. Soon the cows are all starving, and the entire village is faced with bankruptcy and possible starvation.

Notice that it does no good for any one villager to voluntarily keep the size of his herd down. If he refrains from putting more cows on the pasture, he simply leaves more grass for his neighbors' cattle, and increases the incentive for each of them to add still more. As a result, his unselfish action will not prevent the disaster, and he will be poorer in the meantime. Since each herdsman can see that it would be pointless to hold back, each one adds as many cows as he can until the inevitable disaster occurs.

The remarkable thing about this situation is that if each person makes the most sensible decision from his own point of view, the result is that everyone ends up much worse off. What is missing from the commons system is a negative feedback loop to limit the size of individual herds and, accordingly, the size of the total herd, to the level where it exactly matches the rate of growth of the grass.

There are several possible solutions. If there are 50 families in the village, for example, one solution would be to divide the commons into 50 lots and give one lot to each family. In that way, if a particular family put too many cows on their own plot and allowed the plot to become overgrazed, then that family would be the only one to suffer from it. This gives each family an incentive to keep its herd at the right level.

But putting up all those fences would be expensive, and cows are always knocking fences down or getting tangled up in them. It might be cheaper and simpler in the long run to give each family the right to graze a certain maximum number of cows in the open pasture. If the land can support 200 cows, each family would have the right to put a maximum of 4 cows on it.

Still another solution would be to hold an auction each year and auction off 200 grazing permits to whomever was willing to pay the most for them. The money could then be divided equally among the members of the village. Whatever solution they choose, however, it will have to involve some kind of "government" regulation--what Hardin calls "mutual coercion, mutually agreed upon." The "tragedy" of the commons is that disaster is inevitable as long as the original rule of the commons is used. But the interesting thing is that if everyone agrees to give up some individual freedom to the larger system--the village as a whole--then everyone is better off as a result.

The commons problem is still with us in many ways. It typically occurs when the boundaries of a problem are bigger than the largest system which has the power to solve the problem. The original commons was a <u>village-wide</u> problem, but the power to make decisions about it was at the <u>individual</u> level. The solution was either to give the decision making power to a system as big as the problem,

such as a village council, or to divide the problem up into many small problems and give each of the individual decision makers exclusive responsibility for one piece of the problem.

But the second solution is not always possible. There is no way, for example, to fence off the atmosphere, so that pollution created in Newark remains solely Newark's problem, not Manhattan's problem as well. In these cases, the usual solution is to delegate authority upward to a higher-level system, such as the federal Environmental Protection Agency.

One advantage that the United States has, from a systems point of view, is that the area controlled by the national government is big enough to handle most problems which spill over more than one state. In areas like Europe, however, the countries are much smaller and "commons" problems are much more likely to spill over from one nation to another. When factories in Italy create pollution which harms people in Yugoslavia, there is no way to divide up the problem, and no really effective "higher level" to pass the problem up to.

"The Yugoslavs can complain, but there is no way they can force the Italians to stop polluting."

The Yugoslavs can complain, but there is really no way that they can force the Italians to stop polluting, unless they are willing to start a war.

Ultimately, as the world becomes more and more industrialized, problems like pollution become increasingly world-wide problems. Both the atmosphere and the ocean, where all pollutants end up, span the globe, so they really constitute a global commons. As the problems increase, we will eventually need an effective world government of some sort, with the power to make decisions on global problems at a global level. The United Nations is a step in this direction, but so far its member nations have not given it the power to control their behavior.

The Cost of Information: Since the "tragedy of the commons" is caused by trying to cope with a problem at too low a level in a system, it would seem that it could be avoided by simply coping with all problems at the highest level of the system. However, this would mean that the top level of the system would have to make all of the decisions for every part of the system, which means that it would have to have all of the information necessary to make all of those decisions, and information is expensive to collect, store, and use.

Many people complain already about the size of the government bureaucracy, but just think how big it would have to be if every decision on every local matter--whether

to hire a particular teacher, change part of a zoning code, fine a speeder, buy a new snowplow, repair a street --had to be made in Washington! People would have to spend hours and hours filling out forms and giving testimony on the simplest subjects, and then wait months or years for the forms to get to Washington, reach the right person to make the decision, and then be transmitted back again. Nothing would get done, the cost in time, money, and labor would be ridiculous, and the whole system would quickly grind to a halt.

In other words, we have a conflict here between two good rules of thumb. On the one hand, it is quicker, simpler, and cheaper to make decisions at the lowest level possible in the system. On the other hand, it is essential to make decisions at a high enough level in the system to avoid serious "commons" problems. The important thing to understand is that there is no perfect solution to this conflict. Shifting the control of a problem to a higher level may reduce conflicts between subsystems, but it also increases costs and reduces efficiency and flexibility. Giving control of a problem to the subsystems at a lower level increases speed and flexibility, but also increases the possibility for serious conflict.

For most complex systems, the best rule of thumb seems to be: "Make each decision at the lowest possible level, but be ready to shift the control of the situation

to a higher level if a serious problem occurs." Natural systems do this automatically. For example, you do not have to remember to breathe, or consciously think about which muscles to move when you are walking. As long as nothing goes wrong, you can let the lower levels of your nervous system deal with these tasks, and keep the highest level--your conscious mind--free for dealing with more important things. You only have to think about them when you choke, or get dizzy, or something else happens which the subsystems can't cope with.

With the economic and political systems, however, choosing the level at which to deal with a problem is not at all automatic. On the one hand, people often fail to recognize a serious "commons" problem when it occurs, and resent giving up their own freedom to do what they want without government interference; business's hostility to environmental regulations is an example. On the other hand, when people can see obvious imperfections in the system, they often are unaware of the high costs of removing those imperfections.

This brings us back to a point discussed in chapter three--the advantages of tolerating some sloppiness in a system. For example, smuggling is against the law, and it would be desirable to eliminate it completely. To do this, the government would have to know about every attempt to smuggle things into the country. To get this information,

we would have to guard every inch of coastline and border and hire enough customs agents to completely search every person and thing entering the country. The cost of getting this information would obviously be much higher than solving the smuggling problem is worth, so the government chooses to spend only enough money to make smuggling risky, even though that means allowing a good deal of smuggling to continue.

"The government chooses to spend only enough money to make smuggling risky."

The property tax is another example. The tax on a piece of property is based on the property's value, but the problem is that property values are always changing. It is obviously unfair to you if the government thinks your house is worth twice as much as it really is, because then you'll have to pay twice as much tax as you should. Similarly, it is unfair to everybody else if the government values your building at only <u>half</u> of what it is worth, because then you won't have to pay your fair share.

But to send trained and highly paid appraisers out at frequent intervals to examine every building in a community may be so costly that the system would be better off if it simply put up with some unfairness. If there is some way the people who are paying too much can appeal, they will have an incentive to do so and this will solve half the problem; it will then probably be cheaper to let the other group "get away with" paying too small a tax than it would be to spend the money to find out who they are and collect the additional tax.

It's easy to look at problems like smuggling and property taxes in this way, but most people have some issues which they get emotional about. If you feel very strongly that the government should do more about pornography, drug use, unemployment, abortion, racial discrimination, the sale of hand-guns, or some other issue, you may think it would be well worth the cost. Nevertheless, these are all problems which would be very difficult for the national government to <u>completely</u> solve--expensive not just in terms of money, but in terms of growth of government bureaucracy, loss of freedom and privacy, and disruption of other essential parts of the system. Unfortunately, any system has limited resources for collecting and processing information, and this means that it must make difficult and often unpleasant choices about which problems it should pay attention to and how hard it should try to solve them.

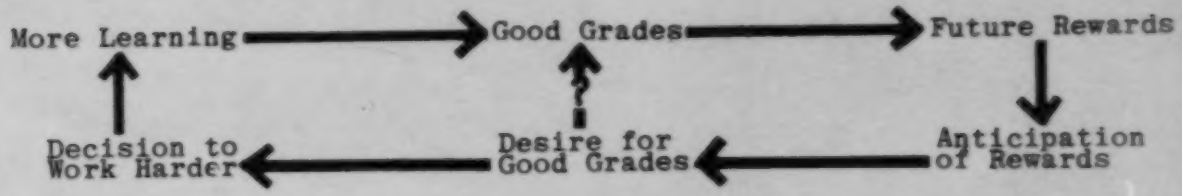
This does <u>not</u> mean, incidentally, that society should

necessarily ignore the problems listed above. That is fundamentally a moral and political decision in each case. It does mean, however, that no society can be perfect--solving one problem almost always creates others--and people need to understand and have tolerance for some degree of sloppiness and unfairness in the system.

"Solving one problem almost always creates others"

The Distortion of Feedback: Still another information problem is that complex systems depend on information to control the behavior of their subsystems, and this often creates an incentive for the subsystems to "lie" or at least to distort the information flow. For example, good academic grades and test scores are intended to be indica-

tors of learning and achievement, but they are also the basis for admission to other schools and to good jobs. Since the students know about these potential rewards, a feedback loop is created which is supposed to look like this:



But if there are other ways to get good grades besides working harder and learning more, students will be tempted to take a short cut, such as studying only what will be on the exam, or cramming for the exam, or cheating, or trying to persuade the teacher to raise the grade, or falsifying the records of the grades. In other words, the student can try to manipulate the symbol instead of changing the underlying reality which the symbol is supposed to represent.

The same thing can happen to many other areas. If people are taxed on what they say their incomes are, they will be tempted to lie about how much money they make. If people in business and government are fired for making mistakes, they will be tempted to hide those mistakes from the people in charge. If politicians need votes to

get elected, they may be tempted to stuff the ballot box rather than persuade the voters. A company with a poor product will be tempted to lie to potential customers in its advertisements.

Grades, tax forms, work records, vote counts, and advertisements are all pieces of information which form essential parts of various feedback loops in the economic and political systems. If people think it is easier to manipulate the feedback loops by distorting the information than by changing what the information is supposed to represent, the quality of the information which the system gets will decrease and so will the efficiency of the system as a whole.

As a result, complex systems generally have to spend a great deal of effort and resources trying to prevent this distortion, either by "checking up" through other channels on the information it gets, or by making the information much harder to distort, or by making the penalties for cheating much higher than the rewards. This constant need to protect feedback loops from distortion simply adds to the cost of collecting information in the first place.

The Loss of Predictability: Finally, the flexibility that enables complex systems to survive in rapidly changing situations also results in a loss of predictability --that is, it reduces the availability of accurate information about what the system will do in the future. This is

conspicuous in economic and political systems. A democracy, for example, is much more flexible than a rigid totalitarian society, but this flexibility also makes it harder to make effective long-range plans in a democracy. Similarly, a modern market economy is able to respond to changes more quickly and accurately than a controlled economy can. But this also makes it much more difficult to forecast economic conditions in a country like the U.S. than in, say the People's Republic of China. Even comparing systems within the U.S., we can see where this holds true. For instance, it is easier for a civil service employee to predict what he will be doing five years from now, than it is for a person working in a dynamic industry like electronics, where the products and manufacturing techniques change almost daily.

The result is that we pay a price for greater flexbility. We are more likely to waste time or money on job training that becomes useless, or investments that turn out not to be needed. Up to a point, an increase in flexibility increases the overall efficiency of the system so much that the price of uncertainty is worth paying. As the rate of change increases, however, the costs of uncertainty begin to climb more rapidly, and it becomes more and more important to keep them in mind and to minimize unnecessary changes and losses of predictability.

Summary: At this point, you should begin to have a working familiarity with the basic ideas of systems thinking, including a feel for the common patterns of organization and behavior that characterize most dynamic systems. The next step is to apply some of these ideas to the big, complicated systems that make up the world we live in. In Part Two, we will look first at the ecological, economic, and political parts of our environment, and then at some of the problems affecting the total system.

PART TWO

ENVIRONMENTAL SYSTEMS

Chapter Seven: EVOLUTION AND THE ECOSYSTEM

Evolution is the history of the gradual development of the species, or different kinds of living things, which make up the ecosystem of our earth. An understanding of how evolution works is essential to understanding the nature of the ecosystem of the entire earth, and of smaller sections of it. Evolution is the working of the ecosystem through time, the history of the natural life-systems around us.

Change in the ecosystem comes from reproduction. Genes--giant molecules in each cell of an organism--carry the coded "blueprints" for that organism in the form of programs which control the way the cells are

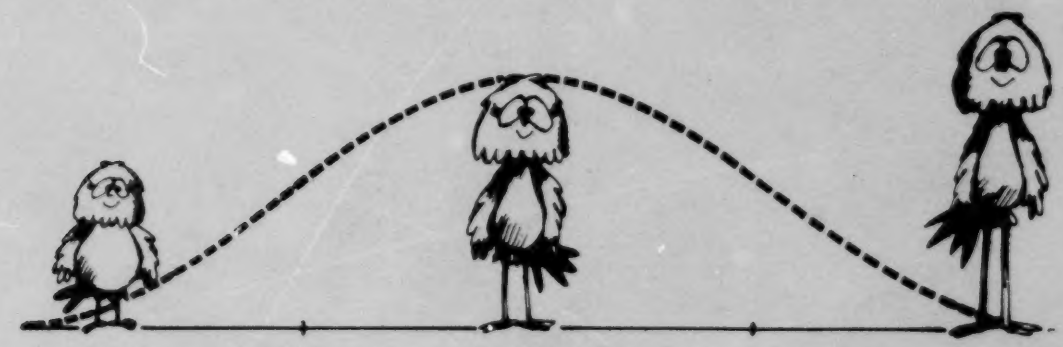
organized and tell them how to do their jobs and when to reproduce. In order for a living thing to reproduce, a set of these instructions must be provided for the new creature. Very simple organisms, like the one-celled ameoba, reproduce by growing and dividing. Each amoeba duplicates its genes, and then divides into two new organisms, each having the same genes. Obviously, the amoebas which are descended from a single ancestor are all almost identical with each other. Basic changes in these organisms' designs can happen only by accident, when the process of duplicating the genes does not work properly. The amoeba as a species is thus fairly slow to change. When their environments change, when new circumstances turn up in which their chemical and physical programs do not work, the organisms simply cannot survive.

The Reason for Sex:

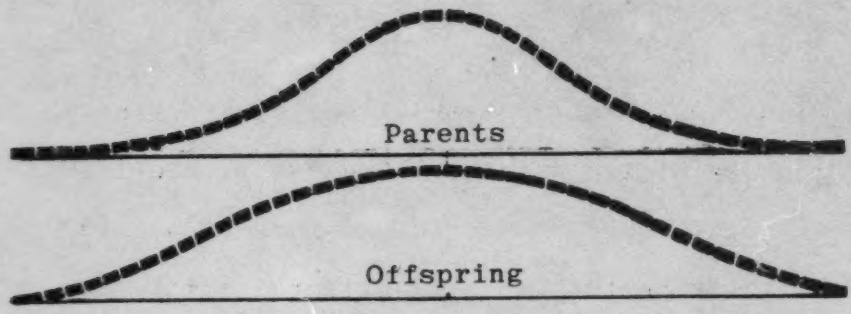
Sexual reproduction permits species to come up with a wider variety of fixed programs more quickly. In sexual reproduction, two different organisms contribute genes to the offspring. Each offspring will have different genes in different combinations than its parents had. Thus, it can have a different set of programs or "traits." A trait may be height or weight, shape or color, internal chemistry or bone design, or any of thousands of variations which

enable that individual to function slightly differently from other members of its species. Because it provides for variety within a species, sexual reproduction makes it possible for living things to adapt more rapidly to new situations without waiting for accidental changes in the genes.

Here's how it works. If you check a group of individuals of the same species for any single trait, you will find the trait is <u>randomly distributed</u> among the individuals. Counted and plotted on a graph, the trait would usually appear in the shape known as a "bell curve"--which simply means that a few members of the species would have much less of the trait than average, a few much more, and the greatest number about the same average amount. A bell curve for height in adult Americans would look something like this:



Because of the way sexual reproduction works, scattering variations of a particular trait within the population, the offspring of a population will have the same <u>average</u> for a trait that their parents had, but its distribution will be slightly more spread out.



In other words, extreme examples of the trait will keep appearing as new combinations of genes are made in the reproduction process.

That is, provided nothing else influences the new generation. If, however, the individuals on one side of the average have more offspring who survive than those of the other side, the average for the next generation will shift toward the more successful group. If the same thing happens to one generation after another, the species will continue to evolve in that direction; the average of the trait would increase or decrease for the whole population. What would cause the individuals at one side of the curve to have more offspring than other members of their species? One possibility is that the trait they share helps those individuals to survive better, allowing more of them to survive until they are old enough to breed. They will thus, as a group, be able to have more offspring.

Traits which help individual organisms to survive are those which help them do a large number of things: gather food, use available food efficiently, avoid being eaten,

avoid accidents and disease or recover from them, cope with climate changes, find and attract desirable mates, produce healthy young, and raise their young to breeding age. Successful traits are all successful relative to the environment in which the organism lives, and to some program the organism must carry out in order to survive and reproduce. That is, successful traits are successful within the larger system of which the organism is a part.

There are at least three basic systems which all organisms are members of: the larger ecosystem which surrounds them and provides their habitat, the food and predation cycle which directly affects their eating and being eaten, and the reproductive system composed of members of the same species. Evolution toward traits which help individuals adapt better to all of these systems happens all the time, so evolution cannot be a change in just one trait at a time. Instead, an evolving organism acquires combinations of traits that work well together in all the basic systems in which the organism lives.

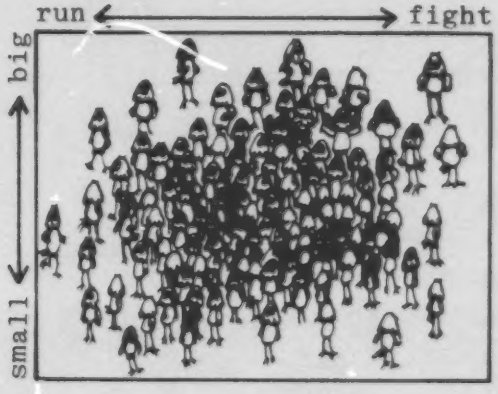
Individual traits, after all, frequently conflict with each other and require trade-offs. A large, strong individual may find it easier to avoid being eaten, but harder to get enough food to fuel its larger body. An

organism which produces large numbers of young might stand a better chance of having a few offspring "get through," but one which had fewer babies could protect and nourish each of them better, and thus increase their chances. Plants with a bitter taste may avoid being eaten, but those with edible, tasty fruit can have their seeds scattered to a wider choice of possible growing places by the animals which nibble at them. Animals which are colored to blend in with their surroundings will more often escape predators, but they may also pass unnoticed by members of their own species with whom they need to mate.

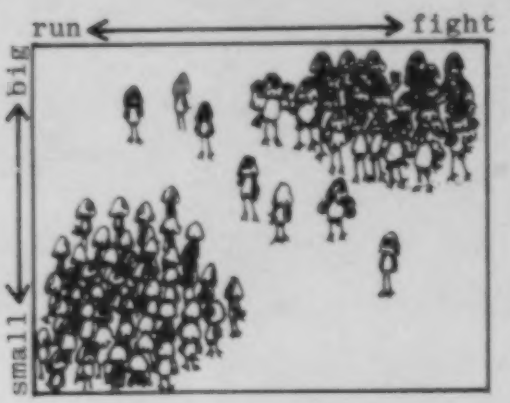
As a result of such trade-offs, sometimes the ends of the bell curve survive better than the middle. The bitter plant and the tasty one might both do better than the average, unappetizing, but not nasty specimen, depending on the range of places in which the species grows. An animal species that wanders over grassland and through forest might have some members that climb well and some that dig well; if the climbers do better in the forest and the diggers do better in the grasslands, the two ends of the curve might gradually evolve in opposite directions. Many generations of such evolution can result in two different species descended from the same ancestors, such as the tomato and the deadly nightshade, or the squirrel and the field mouse.

"If climbers do better in forests and diggers do better in grasslands, the two ends of the curve might gradually evolve in different directions

In these examples, we have concentrated on single traits. But no living creature can afford to do so. It needs systems of traits that work together well, and it will gradually evolve them or die out. For example, the trait of size might be related in some animals to a trait of "courage." Some of the members of a population might be large, some small. Some are more likely to run and hide and others are more likely to stay and fight. The random distribution of these two traits would make a "sprinkle" effect like this....



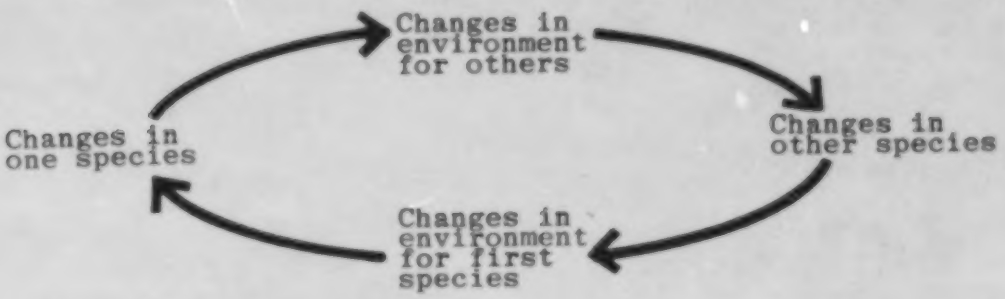
with most of the animals in the center: medium sized and of average courage. The few who are big and brave and the few who are small and cowardly are likely to survive pretty well. But most of the small ones who stay and fight will lose, and most of the big ones who try to hide will be easy to catch because of their greater clumsiness and visibility. So, in the next generation, we could expect more descendents of the animals with traits that match well--more small hiders and more large fighters.



If the animals' environment remained pretty much the same, the chart would become more like this, and the population would be well on its way toward splitting into two separate species. A great many other traits would also be involved. In addition to being big, the most successful fighters would probably have sharper teeth and claws, thicker hides, and heavier bones. The best of the hiders would be light-boned, agile, fast, and protectively

colored to blend into their surroundings--not just smaller. The individuals who are best equipped in all their traits to survive in the system of which they are a part are the ones who are most likely to produce the next generation.

The environment in which an organism lives is a feedback system. A change in the larger system causes changes in its members, and changes in the members also


Changes in environment for others
Changes in other species
Changes in environment for first species
Changes in one species

change the system. A species can change its environment. Mosses and lichens help eat away the rocks on which they grow, breaking them down into sand and soil in which other plants will thrive. Water birds carry the seeds of marsh plants to lakes, spreading plants that clog the lakes and eventually form swamps.

The most spectacular example of the way species can change their own environment was also one of the earliest. When life began here on earth, the atmosphere contained little oxygen. The first living things did not need oxygen. Many of them, however, produced oxygen as a waste product. Gradually, the oxygen accumulated, "polluting" the atmosphere and creating problems for the

creatures that produced it. Most of these creatures died, but some adapted themselves to places where little oxygen penetrates and others evolved the ability to live with the new environment. In short, they met the challenge of an environmental change they themselves had caused.

The most important part of the environment of any species is other living things, and each species forms part of the environment of many others. A particularly important relationship between two species is the predator cycle discussed in earlier chapters. The predator cycle frequently provides the feedback which brings about evolutionary change. If the predator catches one kind of prey more easily, this puts pressure on its prey to evolve in a certain direction and then the changes in the prey put similar pressures on the predator. If owls catch slow, dull-eared mice most easily, then more mice will soon be descended from the quick, sharp-eared survivors. But if mice become harder to catch, noisier or clumsier owls will tend not to survive, and owls will evolve into better mouse-hunters, putting still more pressure on the mice.

The feedback relationship between two species in a predation cycle can produce strange results. Long before birds developed, insects found trees good places in which to lay their eggs, because they were high up and safe from things which ate the helpless grubs. When birds developed, they found the grubs a good source of food. The insects that could hide by digging deeper into

the bark survived. But by the same token, birds with stronger beaks and neck muscles for digging after the grubs were also more successful. In time, surface insects evolved into wood borers, and simple insect catchers evolved into woodpeckers. The same process accounts for many pairs and groups of species. Joined to each other by a larger feedback system, these species evolved together in complementary directions.

Besides adapting to its surroundings and to members of its predator and disease systems, the evolving creature must adapt to other members of its own species. We mentioned earlier that sexual reproduction was itself an evolved trait which helped species accommodate themselves to changes in their environments. It is important to remember that ordinary sexual reproduction is the main source of evolutionary change. Accidental changes in the genes--mutations--are responsible for only a very small part of this process. After all, when a creature with a mutation-- a "mutant"--is produced, it must face the same environmental challenges as a normal member of its species.

Only if the mutant's new trait helps it to adjust to the environment better or make more efficient use of the environment will the mutant survive. If a mutant plant has leaves streaked with white, for instance, it might survive in less shady parts of its habitat than other members of its species. If a mutant animal has a new digestive enzyme

which lets it eat a different family of plants, it might find more food. Under such circumstances, a positive feedback process is set up, and a successful mutation spreads within a species fairly rapidly. But most mutations are not successful. These changes take place randomly, in no particular pattern, so they are more likely to be harmful or out of balance with other traits. The mutant usually dies long before it can pass its mutation along to offspring. In organisms that reproduce sexually, normal variations within the genes of a population, not mutations, are the usual source of evolutionary adaptation.

Thus it is very important that the evolving creature adapt to other members of its own species, as well as to its general surroundings and to members of its predation and disease system. It may seem obvious that members of a species must be able to find each other to mate. Yet this can be a problem. Whales move freely through the immense oceans. The whales who can easily locate other whales and who can make themselves more easily found tend to mate more successfully, and so pass on their traits to offspring. As a result, many species of whales developed voices which are capable of making long, distinctive "songs" that are recognizable for hundreds of miles through the water. Similarly, woodpeckers use their strong beaks on tree trunks to rap out courtship signals

in addition to boring out grubs for food. And the bright plumage and songs of many other birds have the same function. In many species, the male is bright and highly visible but the female, which must spend more time on the nest, is camouflaged for protection.

The process by which members of the same species choose their mate naturally tends to set up a positive feedback loop for characteristics which the group shares. Plants pollinate others which grow nearby in similar conditions, or which attract the same pollinating insects. Thus the ability to tolerate light and shade, or the color and scent of a blossom, shared by both parents, are more likely to appear in the seedlings. Similarly, animals will tend to mate with others having the same strategy for coping with the environment. The fighters join a group of other fighters and the hiders find their mates among other hiders. If fighters mated with hiders, their offspring would probably be mediocre at either strategy. The tendency of individuals to select similar individuals as mates is a useful trait for species which reproduce sexually. Without it, organisms would probably have their other beneficial traits cancelled out by a match of opposites. With this tendency, the system adds another positive feedback loop which speeds up evolution and adaptation.

"The tendency of individuals to select similar individuals... is a useful trait"

When people work to develop domestic plants and animals with certain qualities, they often arrange for inbreeding. This involves pairing similar, usually closely related individuals to capture traits people want. Champion pups of the same litter are bred with each other to establish their good traits in their offspring more rapidly and surely than "open" breeding could do. Inbreeding permits rapid and sometimes extreme development of special traits. Small, isolated islands also often show the effects on inbreeding on a natural population. The Galapagos Islands, off the coast of Chile, are famed for their peculiar species of animals which are all strangely adapted to their

small, inhospitable home and to each other. In fact, the ecosystem of the Galapagos islands caught Charles Darwin's attention when he visited there during a scientific expedition, and led him to the idea of natural adaptation and evolution which he explained in THE ORIGIN OF SPECIES and which we are exploring here.

Such severely limited inbreeding makes for dramatic results. But even in their natural state, many animals inbreed. Since most creatures that reproduce sexually find mates with similar traits, their choices are limited to the group within their species which is most similar, and probably most closely related, to themselves. To further take advantage of a positive feedback loop for evolutionary change, most mammals tend to form breeding communities. Almost all the members of a community, numbering perhaps 1000 individuals, will find mates within the community. Only a few, perhaps 2% or 3%, will mate outside the group.

Within this system, a trait valuable for the community's own region is quickly passed on and reinforced by inbreeding. At the same time, the small number of "outbreeders" continue to bring into the community traits from other members of the species which might prove useful later. Thus, animals' preference for a breeding community of a certain size tends to become locked in as an instinctive trait because it helps speed up the evolutionary process.

Oddly enough, death from old age is another evolved trait which speeds up evolution. Higher animals reproduce only during part of their lives, and they wear out within a fairly predictable life span. This prevents the same individuals from competing with their own descendents or contributing their genes to new generations indefinitely and thus continuing the same old traits. In other words, the reason for death is the same as the reason for sex: both help increase diversity and speed up the process of evolution. Thus, along with other traits good for survival, living things may evolve the ability to evolve more efficiently.

Evolution and Complexity:

Is there a direction to evolution? Is it going anywhere? From what we have seen so far, you can see that the answer is yes. Evolution is directed toward more specialized, more complicated living things. This is not to say that simple creatures are unsuccessful. The one-celled protozoa are literally all around us and inside us, surviving splendidly and helping us survive . Many of them are identical with their ancestors from before the origins of the mammals. They are marvelously adaptable, making themselves necessary to the life of plants and animals in water, in soil, and even in our digestive systems. The protozoa can be likened to a very rugged system with a fixed program. To gain any

advantage over them, another form of life would have to have a slightly more flexible system, and be slightly more complex. Perhaps it should be many cells, joined together into a shape which would enable it to catch more nutrients from the water in which it lives. Some of these many-celled animals might evolve the ability to float on top of the water to catch other floating organisms. Others might survive best by attaching themselves to rocks below, perhaps even protecting themselves with hard crusts or shells. Still others might evolve the ability to swim through the water looking for food and avoiding danger. Eventually these different types would evolve into jellyfish, clams and corals, and fish of many varieties.

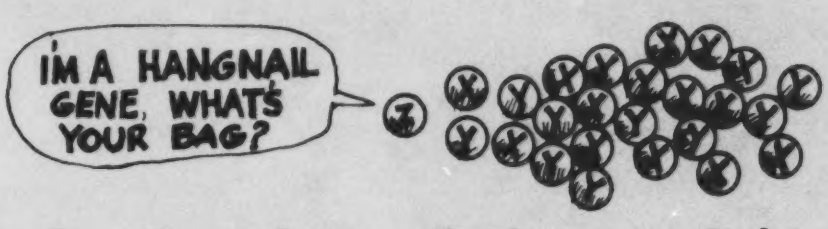
Amphibians such as frogs, salamanders, and turtles can live on land as well as water, avoiding trouble by switching back and forth from one habitat to the other. Reptiles do far better on land than amphibians, since they can move more quickly and are protected from drying out by their scaly skins. Their young are not helpless tadpoles, but smaller versions of the adults, able to move about and fend for themselves. Some reptiles became meat-eaters, some became plant-eaters. Some even took to the air, and eventually developed into birds.

The more specialized evolving species become, the more opportunities for further specialization they offer

to other species. Thus the wood-boring insects, by escaping other birds, hold out to woodpeckers the promise of their own private food supply. The primitive mammals who were small, fast runners escaped their predators. They opened the way for fast, hard-hooved, herd animals. And the faster prey offered the faster predators their own private food supply, if they could only catch them. A typical result is the thin, streamlined antelope and the cheetah, with its hips hung freely from its backbone so that it can take a series of lightning bounds in pursuit. The sturdy, unchanging simple creatures have staked out their claims. The rest of the ecosystem gets divided up by more complicated living things which take smaller and smaller pieces from more specific parts of the "pie." And as more complicated species evolve, they create a more complicated environment for each other to adapt to.

How can one tell, absolutely, how "complicated" a living thing is ? There is a simple measure. Each living thing, in each cell of its body, carries the genetic "information" by which it is programmed to grow and reproduce. The functions of each of its cells are recorded as strings of chemical compounds--genes--in the center of each cell. A bacterium contains 10,000,000 separate pieces of information. A human being, that

recent arrival on the evolutionary tree, has 20,000,000,000,000,000,000,000,000--that's 20 octillion, or 20 billion billion billion--bits of information in every cell.



"Each function of its cells is recorded in the form of chromosomes"

Behavior, too, is a measure of complexity. A fixed program for any single part of the animal's behavior requires far fewer "moving parts" than a flexible program. For instance, a species may succeed in reproducing itself if it has a fixed program for producing a huge number of young. A frog may lay thousands of eggs at once; then the defenseless tadpoles are left to chance, and only a few of that huge number actually survive into adulthood. On the other hand, most birds lay only a few eggs at a time. These are carefully protected, and the young are fed, cared for, and trained by the adults until they are fully able to take care of themselves. When they leave the nest, they are not only physically mature, but they

are also "educated," taught to recognize predators and to defend themselves or hide successfully. Each of the young birds has a far better chance of survival than a tadpole. And its early rearing has prepared it for a life of flexible behavior--of learning.

Specialization means the tendency of one individual or species to do only a limited number of things. In a simple sense, we can say that the woodpecker, which lives mostly on the insects it finds under the bark of trees, is highly specialized in relation to its food supply. The Antarctic penguin is specialized in relation to its habitat. Specialization on a fixed program enables a living thing to do very well in one particular place, as long as the situation does not change. A still more valuable form of specialization is that which enables the individual member of the species to specialize. Pigeons, for instance, are well adapted to gathering food in a large city or to surviving on barren cliffs and mountains, because each individual pigeon can readily learn a new program to meet different circumtances. A city pigeon, a mountain pigeon, and a pet homing pigeon will have very different "specialties" for getting food, nesting, and rearing their young. Yet all the pigeons are essentially alike in their talent for learning. This species has achieved individual specialization by means of flexibility.

Generally, evolution moves toward this kind of individual specialization as well as toward species specialization.

Earlier species tend to be more uniform. Individual members of them tend to look and act more alike. Amoebas which reproduce by budding off indentical twins of the parent are all completely alike. Some fish may have distinguishing individual markings, but their habitats and habits are strictly predictable. But in the "higher," more complex species, individual members look and act distinctly different. Any casual observer can readily distinguish the pigeons on a city street, both by their looks and by their manners. And the differences in behavior among higher animals is not just the result of their rearing. They seem to have inborn temperaments. One puppy will be bolder, another more cautious. One usually chooses the direct way, the other tends to act more subtly. The variability of the species enables individual members to adapt to their changing circumstances most effectively.

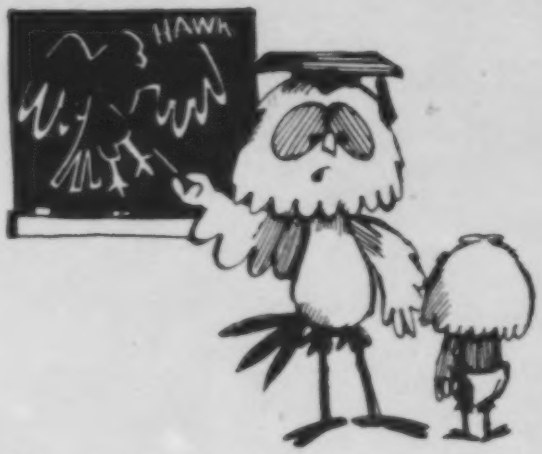
Evolution--i.e., gradual adaptive change--tends to increase the complexity of a system and the specialization of its parts. This is true of social systems as well as natural systems. Primitive societies of human beings, especially those found where the development of the society has been delayed by very harsh conditions or continual threats from other neighboring peoples, have a few basic "jobs" in the society, and members of the society do most of these jobs themselves. Each family makes its own clothing and takes part in finding or raising all the

food it uses.

A modern society, however, which is the result of many centuries of relatively peaceful, fortunate growth, actually coordinates hundreds of thousands of different "jobs," and individuals are very unlikely to do more than a few for themselves. A production worker might make, not cars, but the steel frames of the cars. A doctor might treat only children with heart disease. Thus the worker and the doctor can amass very detailed knowledge and acquire very particular skills in their lines of work, and do their jobs far more efficiently than a non-specialist.

But if the society is to be able to change with changing conditions, its members must be able to learn well. They must learn jobs, and then unlearn them and master new ones. And all the time they must learn how the immense system of which they are a part works, so that its complexity will not be baffling and defeating to them.

The greatest source of individual specialization in society and in natural systems alike, is learning. Like sex and death, learning increases diversity and flexibility and therefore greatly increases the ability of a



"Learning greatly increases the ability to adapt"

system to evolve and adapt to a changing environment.

The increasing specialization and complexity of the ecosystem, which naturally results from evolution, also makes the system increasingly efficient. Species evolve to use all the possible channels of food or energy. These channels may be seen as stages: from sun energy which is used by plants to manufacture their food (photosynthesis); to plants, which are eaten by herbivores; to the herbivores themselves, which are eaten by meat-eaters; and finally to parasites and decay organisms which feed on the meat-eaters and plant-eaters.

Each stage contains species which are highly specialized to win food in even the most difficult conditions. Plants have evolved an enormous variety of strategies for making the best possible use of available sun energy. Red seaweed is red so it can store the light from the sun where sunlight is scarce. Kelp, another kind of seaweed, has air-filled floats along its stalks, to bring the plants up near the surface of the water, where sunlight is plentiful. Lichens, plant systems made up of separate cells of fungus and algae, combine the photosynthesis of algae with the fungus' talent for drawing minerals and water out of the ground.

All these plants make calories--edible energy--out of the direct rays of the sun. Each of these adaptations of plants was an opportunity in the evolution of plant-eaters, who developed the digestive systems to break down

the tough cells of plants and extract nutrients from them. Plant-eaters range from the termite, which digests wood fibers with the help of friendly protozoans in the termites' stomachs, to such large grass-eaters as the elephant. The blue whale, the largest living animal, supports itself on the microscopic single-celled plants which float in seawater. All of these vegetarians convert the chemicals in the plants into energy and into the proteins and other complex chemicals which make up the bodies of animals.

In turn, animals which are unable to digest plants, but which derive their energy and protein from other animals, arrived on the scene. There is no plant-eater so unlikely that some meat-eater will not eat it. Most successful meat-eating predators have evolved the ability to hunt many different prey. Otherwise, they are at the mercy of the supply of their single preferred food. The bobcat, which eats any small woodland creatures it can find--including mice, squirrels, moles, gophers, game birds, and chickens from nearby farms--will seldom run out of food. The ant-eater, which relies on large nests of insects to feed its large bulk, is more likely to be caught in a boom/bust cycle with its favorite food.

The energy levels we have described thus far are in increasing order. At the lowest level, plants use energy to manfacture the complex chemical compounds of which the plants are made. At each higher level, simpler compounds

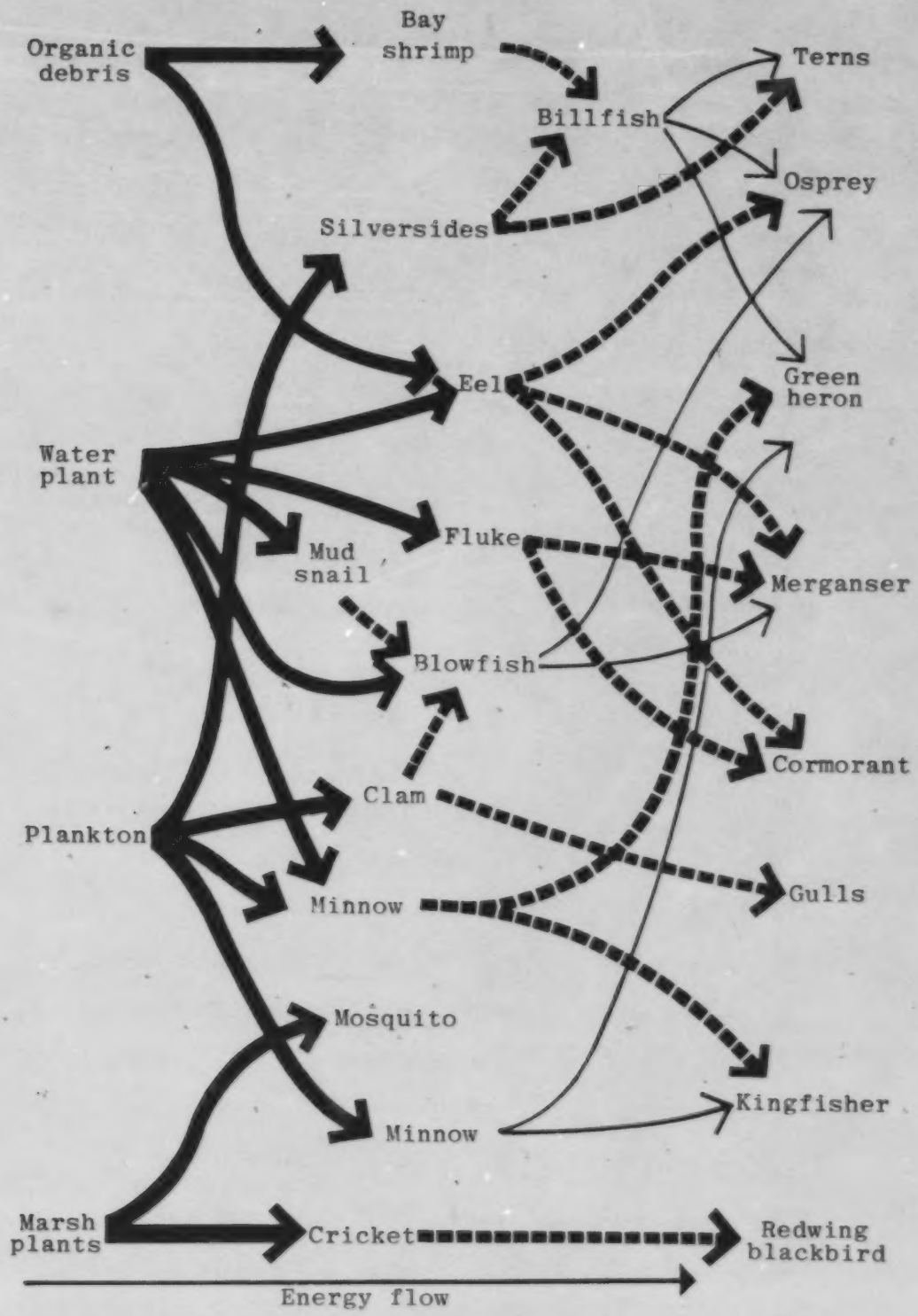
are further combined to make more complex substances of which animals are made. In addition, plant and meat-eaters both get the energy to fuel their systems by breaking down their food to release the sun energy that plants and plant-eaters have captured. The plant and meat eaters cannot derive food energy directly from the sun. So our first three levels all represent increases in the chemical complexity and energy level of organisms. Of course, the meat-eater level may be duplicated, with small meat-eaters falling prey to larger ones. Energy in the form of food is passed up the ecosystem from level to level, and so are chemicals required by the living things in the system, and even some chemicals which are harmful to them, such as man-made poisons.

Finally, all of these organisms, including the meat eaters, are food for the parasites and decay organisms, which break down the complex chemicals of both plant and animal life back into the energy and simple compounds of which they were made. They complete the growth and decay cycle, always restraining the growth of the other parts of the system and bringing it back to equilibrium. Here again, we find plants, the fungi, which do not photosynthesize, but feed on the more complex chemicals they break down, and a wide range of specialized animals, from micro-organisms to dung-beetles to scavengers such as the vulture.

The ecosystem in any single type of region will have

its own distinctive array of plants and animals at all of these four levels of energy and food. All the organisms within the ecosystem will have evolved in relation to each other, adapting to the opportunities offered by the other living things in the region. As a result, we must expect to find a much more complicated set of inter-relationships than those we have mentioned up to now. Each plant will have its own effects on the plants near it. Each plant and meat eater will probably eat many different kinds of plants and other animals. On the next page is a chart, still highly simplified, of three of the four levels of a salt-water marsh, showing the inter-relationships of plants, plant eaters, and meat eaters. (The parasites, scavengers, and decay organisms which close the loops have been excluded.)

By looking at this chart you can see that no single plant-eater is likely to get out of control because there is negative feedback from several species of meat-eaters. In turn, the meat-eaters are not likely to suffer from exhaustion of their food supply, because most of them prey on more than one species of plant-eater. Some even enjoy other meat-eaters. Can you spot the weak links in the chain? The cricket and the redwing blackbird are the best candidates for a boom/bust cycle. If the blackbirds decrease in number, the crickets will multiply unchecked; when the blackbirds recover, they will soon eradicate the crickets and then starve. Luckily, however, the crickets are also



(After Ehrlich and Ehrlich, Population/Resources/Environment; W.H. Freeman, 1970; and Woodwell, "Toxic Substances in Ecological Cycles," Scientific American, 1967.)

kept in check by their watery surroundings. Also, the gull could be in trouble if human clam-diggers move in in force. However, gulls also play a role as scavengers in the fourth level, not shown on this chart, so they could shift from clams to human garbage dumps. From this simplified portrait of an ecosystem we can conclude that the specialization and complexity which evolution promotes at all levels of energy use makes for a more stable ecosystem.

Let us check that conclusion by looking briefly at a simple ecosystem. In climates or terrains which are naturally hard to live in, such as the arctic and antarctic, very high mountain peaks, or the depths of the ocean, ecosystems are simpler. They may have only a few different species at each energy level. Of course, these species are well adapted to survive in their challenging environments. But because the ecosystem as a whole is simpler, it is more likely to suffer severe upheavals. For instance, in the arctic regions of Scandinavia live the lemmings which were mentioned briefly in Chapter 4. These small rodents are among the few plant-eaters of a region with very sparse vegetation. In turn, they are kept in check by a few meat-eaters, the marten, the arctic fox, and the snowy owl. When the plants eaten by the lemmings increase briefly, a disastrous positive feedback loop is set up. The lemmings multiply wildly, and their predators cannot check their numbers. More predators come to the feast, including

"The lemmings multiply wildly, and their predators cannot check their number."

birds from hundreds of miles away who usually eat fish. Nonetheless, the lemmings increase to such a point that they go berserk and make long migrations to escape the overcrowding. Most of them finally die of the last negative feedback loop--their own over-worked adrenalin glands. After the dramatic upset of the lemming migrations, arctic life settles back down to normal. Balance has been temporarily restored to this simple ecosystem, but only by drastic measures.

It appears, therefore, that the kind of complexity that gives an ecosystem stability is one based on checks and double checks for all the feedback loops in the system. In other words, the ecosystem needs many specialized species, but it also needs a fairly even distribution of these species

at all energy levels in the system. The plant eaters like the lemmings, which are only kept in check by predators, are much more likely to get out of hand than the plant-eaters who must first compete with many other plant eaters for their food. Then any increase in plants to eat will cause slight increases in several different species. Diverse time constants can also cushion the system. A tropical jungle includes an enormous variety of species because its moist, warm climate is so friendly to life forms. Its plant-eaters range from snails and insects which multiply very rapidly, through rodents basically similar in life span to lemmings, up to elephants, which take two years to produce young, and many more years for the young to mature. A change in vegetation in the jungle is quite unlikely to cause an explosion of any single species.

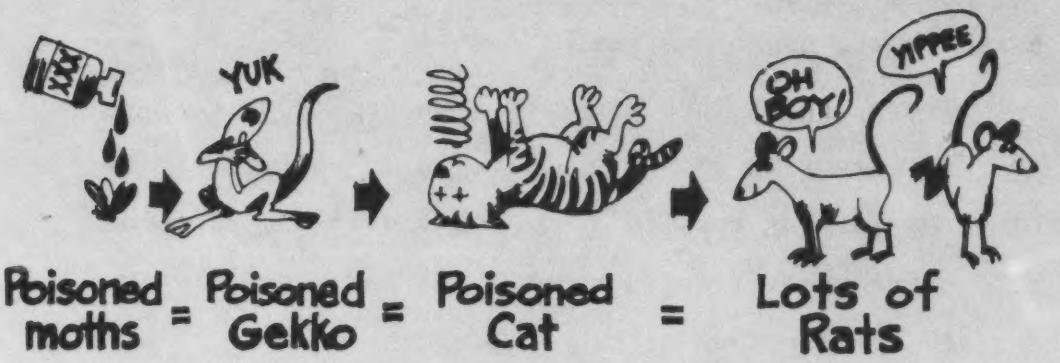
Then, too, the species in a tropical jungle form a large number of subsystems within the single large system. The arctic tundra is dominated by the lemming-fox predation cycle and a few other such cycles which are apt to erupt similarly. A tropical jungle is organized in many interlocking systems. The plants which support other life are themselves arranged in tiers, from the forest floor and swamps and waterways, to the underbrush, the lower branches, and the tree tops. Each tier contains its own plant life and supports its own plant and meat-eaters. A sudden profusion of fruit in the underbrush will be devoured quickly by underbrush birds and beasts, or will bring those from

higher tiers swooping down to join the feast. The whole jungle can react to a change in any part, if necessary, for all the parts of this dense system lie within easy reach of each other. So although the individual species of the jungle are generally far less rugged than those which withstand harsh weather and near starvation conditions in the arctic, the jungle system as a whole is more stable than that of the arctic tundra. What counts is less the nature of the members than the ways in which they are inter-related.

And, finally, an ecosystem's stability is improved by a certain degree of sloppiness, or flexibility in its parts. The arctic seabirds are not so rigidly programmed to their original seafood that they cannot come inland during lemming explosions to provide negative feedback where it is particularly needed. In a tropical jungle, an explosion is far less likely to happen than in the arctic, because many meat-eating predators there are similarly flexible. The piranha of Amazon Jungles presents flexibility in a meat-eating predator carried to an extreme. Swimming in large schools, these fish will strike voraciously at just about any sizable living creature which falls into their waters.

The complexity of natural ecosystems poses problems for human beings wishing to make their own places in their systems more comfortable. In earlier chapters, you saw examples of tampering with ecosystems and trying to outmuscle them which brought unwanted results. Now you can see that many of the disappointments of people's tampering with the ecosystem are caused by the nature of the system itself. Such tampering is not wrong in itself. Some species could be entirely eliminated from the human ecosystem without causing any undesirable effects. Smallpox has now been stamped out everywhere in the world and its extinction will not cause problems. The disease attacked only one species--human beings--and that species is complex enough to be prey to many other pests. In other words, smallpox had a relatively small role to play in stabilizing our ecosystem, because it was part of only one subsystem and operated on only one energy level, where it had plenty of competitors.

In a more usual case, however, a pest is part of a much more complicated subsystem, and has effects at many system levels. For instance, in Borneo, a type of moth whose larvae fed upon and weakened the thatched roofs of houses seemed like a nuisance which could be safely and easily eliminated. However, when the moths were poisoned, the poison was passed up the food chain, first to the moths' natural predator, the gekko, a small harmless lizard,



and then to another meat-eater, the house-cat, which preyed on the gekkoes. Unfortunately, the cats were the main predators of the rats. Without cats, the rat population exploded, and soon the rats were consuming grain, spreading disease, and doing much more damage than the moths had. Poisoning the moths seemed like a good idea, but its unintended effects on the Borneo ecosystem were disastrous.

Only within the last century have people learned to make insecticides and other chemicals capable of being carried up the energy levels of an ecosystem. Until recently, the Borneans controlled moths in their thatch simply by killing the moths. Their actions might harm the house gekkoes, but they could not affect the cats--or the rats. Furthermore, until recently, the inhabitants of a single household or village might have tried to kill off the moths, but their neighbors would have no reason to join them until the experiment was proven effective and safe. But with more effective weapons and better organization, people's tampering with their environment now

assumes more dangerous forms.

Today, humans are capable of making major changes in the ecosystems in which they live, with spectacular and often disastrous results. One example is the Aswan dam across the upper Nile in Egypt. The dam was built to control the flooding of the Nile, which waters all of Egypt, and to generate power for industry and mechanized farming. It succeeded in both objectives. But its other effects were very costly. The flooding had brought rich silt to the fields. Without it, fertilizers, which require a great deal of energy to make, had to be added. The flooding had also watered the ground. In its place, the Egyptian government installed a complex system of irrigation canals, fed constantly from the dam. Finally, it seemed that the agricultural crisis was past.

But the farmers began to suffer from an epidemic of schistosomiasis, a miserable and long-lasting disease. The disease is carried by snails which live in the irrigation canals where the farmers worked. When farmers depended on flooding to water the fields, the snails died out in the dry spells between floods. Under irrigation, however, the canals stayed wet and the snails multiplied without any negative feedback and infected the people. What had been gained on the one hand by the regularity of irrigation was lost on the other by the loss of labor due to disease.

And finally, the change in the Nile's flooding affected

the Mediterranean sea near the mouth of the Nile. There, the fish had been nourished by the plant life and nutrients carried by the flood waters. Without them, Egyptian fishermen found they had far fewer fish to catch. So this source of food was cut off for the country. Altogether, it is hard to show that Egypt improved its people's place in their ecosystem at all, in spite of the huge expense of labor and materials the dam required.

The ecosystems in which most human beings live today have become more and more closely connected with human social systems. The economic system, by which people use and distribute material things, was the first to act on the ecology. The most primitive farmers, by herding certain animals, clearing fields, and planting certain plants, set up new patterns of evolution and interrupted quite a few old ones. Modern man, capable of converting a great many of the resources of earth to his own use, can make far greater changes in the ecological system. The Aswan dam is only a dramatic example of what goes on around us every day as people seek to use their environment to satisfy their own wants and needs.

In addition, the political systems which people use to decide who shall have power can also cause great changes in the ecology. So huge a project as changing the whole course of the Nile could only be accomplished by the use of a great part of the power of Egypt as a whole along with a great deal of Russian foreign aid . So, to

see how human beings will continue to adapt to the other living creatures and things around them, we must understand how human beings get along with each other in their economic and political systems, and how these systems interact with each other and the natural environment. We will deal with these topics in the next three chapters.

Chapter Eight: THE EVOLUTION OF AN ECONOMIC SYSTEM

Adaptation and specialization, which play so important a part in the development of ecosystems, are also essential in economic systems. For economic systems, like other human social systems, evolve over time. The people in them do not alter physically, but they develop habits and skills which set them apart from other people and enable them to do their own economic work well and enable the system as a whole to function better.

An economic system is simply the system by which people get the material things they need and want. We can understand the evolution of an economic system better if we start with the simplest possible economy, one

in which people have only the bare minimum of what they need for food, warmth, and shelter. This is called a subsistence economy. In this system, people find every day what they need for that day's food. Since they cannot find enough to tide them over while they do other activities, they can never make any changes in their situation. Of course, this is only an extreme and hypothetical example. In real experience, no human society has been so poor that some of its members couldn't accumulate a small surplus. The surplus could then be used to improve their economic situation.

An extra day's food, for example, might free people to make tools of wood or stone with which to kill or cut or dig up some food. Or they might weave baskets to store some food in, so that they could gather more food in a single trip and keep it for several days. One would say that they are investing their surplus, using it to get items which would enable them to get more food or make more efficient use of the food they had. For all practical purposes, the tools would be adaptations which would enable them to live more successfully in their environment. The invested surplus is called capital.

Clearly, the capital which made the new tools possible can now begin to form a positive feedback loop. The tools make people more efficient, and the more efficient they are, the more surplus they have which they can spend in getting new tools. Other members of the

tribe, seeing the new tools, will quickly try to save a surplus so that they can make some too. As a result, the entire tribe becomes better adapted to its environment, and thus better off.

The next great economic adaptation human beings made was the invention of agriculture. Instead of just hunting for food, people began to organize the animals and plants around them to keep them always available. In short, people broke the predator cycle, and began to manage their prey so that they would always have enough. But people couldn't take this step until they could be sure of getting their daily food and still have time enough to cultivate their plants and animals. After all, a gardener must wait months before his labor shows some return. So a greater surplus was needed for this longer-term investment.

Something else was needed, too. People won't go to the trouble to plant and cultivate a piece of ground unless they can be sure of having the plants that grow there. Even a short-term investment, such as speinding a day working on a tool, requires some security.

"Even a short term investment requires some security

People will not willingly invest their own labor in making something if they know that what they make will be snatched out of their hands as soon as it is done. So, in order for agriculture to begin, people had to guarantee to each other that they could enjoy the land they tilled and the animals they herded as their own private property.

The effect of property as positive feedback was strikingly demonstrated in the settlement of our own country. Under the Homestead Act, anyone who lived on and cultivated a piece of land in the unsettled West for a certain number of years would own it outright. As a result, vast areas were settled and the food production of the nation grew rapidly.

With property, further adaptations become possible. For instance, one family with a very fertile plot of land might find it had exceptional luck with wheat, or even with cotton or flax, from which clothes are made. Another family, owning a hilly piece of land, might try cattle for milk and meat, and have equal success. These families have adapted their agriculture to the land. At the same time, they have become more specialized themselves. To get everything they need, they exchange with their neighbors, meat and milk for grain and fibers.

But because they are making more efficient use of their land, they all have more of what they want than they could have had before.

In economic evolution, people adapt not only to their environments, but also to each other's own peculiar talents. We might suppose the families we have mentioned simply trade their farm produce. Each family would make its own tools, mill its own grain, make its own cheese, preserve its own meat, and weave and sew its own clothes. But this situation would not remain that way for very long. One woman in the community might be very skillful at making cheese, or one man might be particularly expert at weaving. She can make cheeses which keep without spoiling, and he can make twice as much cloth in an hour as anyone else. Perhaps they have natural talents which help them, or perhaps they have just gotten into the habit of their work more than others have.

These people might offer to trade their cheese or cloth to the others for more of whatever they want. The others will readily agree. Why? Because they know that, given the same investment of time, effort, and materials, they could not do as well. The others in the community will give up cheese-making and weaving and turn their attention, time, and effort to the specific tasks that they are particularly good at. As a result, the members of the

village will have specialized. And the whole village will be able to make more of what it needs or wants than it did before.

This chart shows you the cheesemakers's business:

Looking at how this subsystem of the village economy works, you can see how to determine the selling price for cheese. Obviously, the cheesemaker would be foolish to give up her cheeses for less milk than it took her to make them, or less food, shelter, and cloth than she herself could make with the same time and effort that she spent on the cheeses. These things are her costs--the cost of her materials, of her tools, and of her labor. Her costs determine the minimum price she can ask.

What is the maximum? Obviously, that depends on the costs of cloth, shelter, and other food in the village. The weaver will not exchange cloth for cheese under his

minimum cost. Suddenly, our calculation seems to have gotten very difficult indeed. We cannot set a maximum price without knowing all the businesses of everyone in the village. How does the cheesemaker know how much to ask?

Because all the villagers are now specialized to some extent, we can imagine them getting together one morning in a meeting place or <u>market</u> to exchange their goods with their neighbors. Each of them knows his own costs. Moreover, he knows what use he wants to make of the goods the others have for sale. One villager might have little need for cheeses; he has a fine supply of dried meat for his winter food. Another, who has grain to offer, must buy some high-protein food--either dried meat or cheese. If the cheesemaker wants grain, she must

offer more cheese for it than the dried-meat man offers meat. A third, who loves cheese, might be willing to give her far more for each cheese than anyone else in the village. But he has only meat to offer, while she needs cloth.

With each of these people, the cheesemaker will bargain, trying to get as much of what she can use for what she has made. Both the buyer and the seller will exchange things they do not want for things they do want.

The village market we have sketched is called a "barter" economy. In it, goods are exchanged for other goods. It's difficult for the weaver, for instance, to get grain if the grain-grower needs no cloth. They will have to set up a three-way trade, perhaps with the woman who makes tools, in order for each to get what he wants. Money would solve their problem. All the villagers might agree to exchange their goods for some object designated as money, which they could be sure of trading for whatever they needed. Any object can be money. Seashells, stones, pieces of metal, written IOU's, are all money if everyone at the market agrees to accept them in return for their goods.

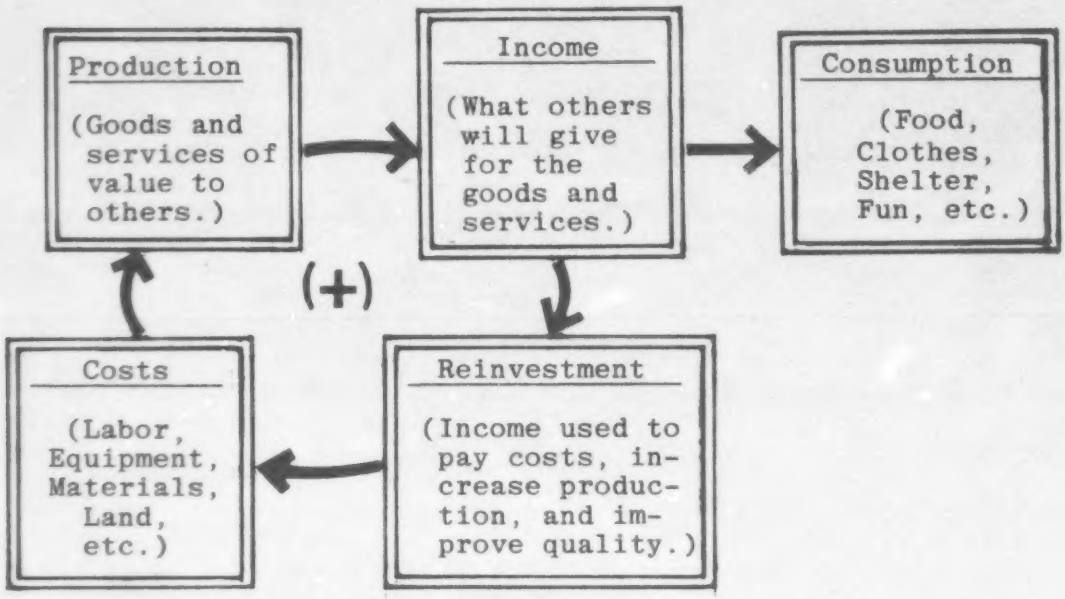
We are used to thinking of money as established and fixed by the government. It is always necessary for the political organization of a society to prevent some people from duping others with counterfeit money which others will

not accept. But even in modern societies, money is not always made by the government. However, it must be acceptable to everyone, since its function is to enable each member of the economy to interact easily with others even though all of them are doing different jobs.

We can now return to the problem of setting a price for goods. The maximum price the cheesemaker can get depends on two things: the number of cheeses (or other protein foods which could substitute for them) brought to the market, which is the supply, and the number of cheeses that people want to buy, or the demand. If many people want to buy a product, and the maker has only a few for sale, the buyers will offer more and more, as in an auction. If several people are selling a product, and most people are already stocked up, the sellers will have to bring their prices down before they can convince anyone to take them off their hands. This process of bargaining helps to balance the supply and the demand.

The "law" of supply and demand is actually a system of feedback. Suppose a supplier gets a higher price for his goods than their cost. The difference between the price and the cost is the supplier's profit. Profit is actually our old friend, the surplus. It rewards the supplier for making something that the people around him need and want. It also contributes to a positive feedback loop, for with this new surplus he can make more investments

to increase his efficiency. The weaver might spend part of his profit making a larger loom on which he can make finer cloth. The seamstress might hire a helper to assist her, so that she can use her skill on the more difficult parts of the work, and so work more quickly than before. As long as these producers make goods more efficiently than others in their economic system, they will get profits, and as long as they get profits, they will have surplus to invest to increase their efficiency.



On the other hand, suppose the supply of a product is so big, or the demand for it is so low that the price falls below the minimum price. Suppose, for instance, that our cheesemaker finds herself selling cheeses for less than cost. Obviously, she cannot keep this up for

long. But there are several ways she can respond to this negative feedback. Remember that she has a flexible program. She might reprogram herself, inventing some way of lowering her costs--buying cheaper milk, making her own utensils, working more quickly. If she does this, the law of supply and demand will have operated to make her more efficient, and the whole economy better adapted to its environment. She might try to alter her surroundings by changing the minds of her fellow members of the economy, telling them how good her cheeses are. (Advertising serves this purpose in a modern society, letting people know what is available and what it is good for. As long as it does not deliberately lie or mislead people, it helps them make better choices about the resources available to them.) Or she might try to increase the demand by making better cheeses--trying new flavors and methods to make her cheeses taste better or last longer.

Finally, the cheesemaker might choose to change her goal. She might give up cheesemaking and try sewing or weaving, just making a few cheeses on the side. This seems to be a waste of her skill. But actually it is good for the economic system of which she is a member. With more people weaving and sewing, the other members of the economy will get more of the clothing they obviously want. And as more people try weaving and sewing, the supply of clothing will rise and the price will fall, so people will

stop moving into the field. In the same way, as cheesemakers turn to other occupations and the supply of cheese drops, the price will gradually rise. Perhaps after a short time, the cheesemaker can take up her original occupation and make a profit at it again. In the meantime, the economy as a whole will not be stuck with an enormous surplus of cheese--or a shortage of clothing.

"The system checks this waste by lowering the reward."

Thus the law of supply and demand, like other negative feedback loops, keeps the system stable, while the positive feedback--profits and investment--makes it grow. When too much of something is produced, the system checks this waste by lowering the reward for producing it. When too little is made, the system offers a reward for making more of what is needed. As a result, the prices of things will tend to stabilize at levels just above cost, with just enough profit to enable efficient producers to become still more efficient.

A producer has yet a fourth course of action open to him. Any producer who cannot get his minimum price in one market can always go to another. Perhaps the neigh-

boring village has little pasture land and needs meat. In that case, the cattle farmer might find it worth his while to take his cows there for sale, instead of offering them in his own nearby market. Of course, the labor he spends in driving the herd to the next village raises his cost, but if the other village is really in need, he might make a fine profit. He might even be able to sell his animals at less than the going price in the next village and still make a profit for himself. This would be the case if one region were much better suited for raising livestock than the other. Naturally, the few cattle suppliers of the new village would soon give up cattle and specialize in raising something more adapted to their own place. In this way, the economic system would be extended to cover several communities within a larger region. Not only would individuals or families within a single village specialize, but also villages within a region, and then regions within a large territory, would specialize to make the most of their particular environments and the talents of their people.

A great part of the history of any nation, and of the world, is the history of how different regions specialized. Often, such specialization takes advantage of special features of the natural environment of a country. Different crops are more successful in different climates and terrains. Holland supplies more than half of the

world's tulips. The plant originated in Asia, but the rich sandy soil of Holland was ideal for raising them because it permitted the bulbs to be easily dug up to be sold. In similar ways, tea was brought to Ceylon (Sri Lanka), rubber to Malaysia, and coffee to Kenya and Uganda. All these crops succeeded in their new homes better than they had in their original habitats, and these countries soon specialized in them.

Not only agriculture, but also industry takes advantage of the natural environment. Many of the early factories in this country were located in New England. The rocky terrain of the region provided many fast-moving rivers, and early industry was dependent on water power for energy. With the invention of steam power generated by coal, heavy industries moved nearer to the coal fields around Pittsburgh and the Great Lakes, where they could use the natural resources more efficiently.

Regional economic specialization opens up a whole new field of labor. The producer will object to using his time and effort to take his goods to distant markets. So he will find someone to do the work for him. A <u>sales-man</u> might be hired by the producer to take the products and sell them. He might be paid a percentage of the price he gets, a commission, as an incentive to take them to the right markets and get the best price.

"A salesman might be hired to sell the product"

On the other hand, someone besides the producer might see a need for a product in a distant market. The broker might buy goods directly from the producer, take them to where he believes they are in demand, and sell them there. His pay is the difference between what he gave for the goods and what he was able to get for them. Since he put his own capital into this venture and stands to lose everything if the goods spoil or the new market has no demand for them, the broker might not bother to operate unless he thinks he can get considerably more than the salesman's commission.

It seems at first sight as if the salesman and the broker actually contribute nothing to the economic system.

After all, when their work is through, there are no more goods than there were when they began. In transporting things from place to place, some may even be wasted or spoiled. So their profits seem rather undeserved. Actually, however, the salesman and the broker perform services which increase the value of the things they deal in, since a thing is more valuable to someone who needs it than to someone who already has plenty. Surely, if the aim of the economic system is meeting people's material needs and wants, then someone who takes goods to places where they are wanted is helping the system succeed.

A more complex economic system has yet another problem of distribution: it must have its producers distributed where they are most needed. When regional specialization progresses, a cheesemaker from the grain-growing region might well consider moving to cattle country. If you want to be in the movies, it's still a good idea to go to Hollywood. To help distribute labor, a whole new system of people movers may be set up, including roads, vehicles, hotels, job agencies, and immigration services.

A third kind of goods are those services which people want and need, just as they want and need material things. Doctors produce nothing, but they make people's lives longer and better, and people are willing to pay for this service. Acrobats, too produce

nothing, but some people would rather hire their services for one thrilling performance than buy many useful products.

Naturally, people who do not use certain services tend to think of them as useless, and to wonder why anyone would pay to have them done. Yet, in many respects, the services which we enjoy or value for their own sake, and not because of any purely economic use they might have, are the things that make us truly human. The spiritual, the artistic, and the just plain fun things are what make life worth living. For people are not only producers and consumers; they use their economic systems to give themselves experiences which are beyond the purely economic.

In addition, throughout a growing economic system, producers and service workers are continually reprogramming themselves to meet changes. Like the cheesemaker, they are changing their own procedures, or changing those around them, or even finding new goals for their work. As a result, a great many of the services offered in an advanced economy are <u>teaching</u> services, from auto repair to psychological health, which will help people reprogram themselves for new ways to adapt to the world and the society of which they are a part.

One important service deserves special mention. This is the service of providing a surplus of capital to another

person. We have said that with a profit, a producer has a little surplus wealth or capital which he can invest in making his own business bigger or more efficient. This capital can buy a farmer more land or better tools. It might even pay for books or travel or schooling by which he can learn better farming skills. But even a farmer who is not yet making a profit can buy these things if he can convince another person to lend him the capital.

Of course, the blacksmith will only lend his capital to the farmer if he thinks that the loan is a profitable investment for himself. In other words, the lender asks the borrower to pay him for the loan. The payment is usually in the form of interest, a certain percent of the amount of the loan (the principal). Like the other prices in a market system, the interest charged for a loan is determined by the supply and demand mechanism, and depends on how much capital is available and how many people want to use it. As with other buying and selling in the economy, brokers to handle the capital market soon come into business.

You might not realize it, but you probably do business with a capital broker at regular intervals. The most familiar capital broker is a banker. When you put your money in a savings account and receive interest for it, you are essentially lending it to the bank so that it may

lend it to someone else, to start a business or buy a home or a car. The bank pays you interest, charges a slightly higher interest from the person to whom it lends the money, and keeps the difference between the two to cover its costs and give it a profit.

The evolution of an economic system, like the evolution of a natural system, leads to greater and greater complexity, diversity, and specialization in its members, and greater adaptation by the whole system to the resources around it. With the growth of their economic systems, people have moved from a subsistence economy, in which people's bare physical needs were scarcely met, to a situation in which most people have enough to survive, with some left over to enjoy and to invest in further growth.

Still, the system, though immensely more complex, is working by its own mechanisms and refuses to be outmuscled. In the process of growth, people make many adaptations that are not successful. Businesses fail, inventions are not adopted, training and skills become obsolete The poorly adapted members of an animal species usually die. But properly speaking, the "members" of an economic system are people's work programs, not the people themselves. With the invention of the automobile, the trade of making

Buggy whip makers "died off"

buggy whips became obsolete. Buggy-whip makers "died off"--that is, they reprogrammed themselves to make other leather goods or even something completely different. Thus the evolution of an economic system can be immensely more rapid than the evolution of a natural system.

Problems in the Economic System

You are now ready to look at several specific problems in the workings of the economic system, and to see how the mechanisms of the system itself can be used to understand and solve them.

Competition. Some societies have regarded competition as an economic problem. After all, it does seem a waste to have more than one or two people or companies making each item people in the society need and want. Why do we need more than a hundred brands of soap? Why shouldn't there be just one automobile company, using the most

modern techniques and turning out the best-designed cars possible? To answer this question, we should investigate how competition works in relation to the law of supply and demand.

As an example, take a simple business you might start yourself. Suppose you make leather belts for a cost of $5 each. If you sell them for a price of $6 each, you find that you can sell 100 a week, and earn a profit of $100 per week. If you raise the price to $15, fewer people will buy, but perhaps you discover that you can sell 50 at that price, and so make a profit of $10 per belt, or $500 per week. So you set the price at $15 and get set to watch your profits flow in.

At this point, however, competition begins. Other people are bound to notice that this is a profitable business, and they will decide to start making belts, too. Suppose someone else begins to sell belts almost like yours for only $14. He might sell 55 belts every week and make a nice profit of $495 ($9 x 55), only a little under yours. Very few customers will buy your goods when they can have his for less. A price war begins. You cut your price below his, and he cuts his below yours. Soon neither producer is making much profit, and you must share your customers with your competitor. At last, profit gets so low that maybe the latecomer drops out of the business and turns to making sandals or handbags. You

might find that, if you charge $9 per belt, you can sell 90 belts a week with no further competition from him, and so make a profit of $360 ($4 x 90) a week. This is the best you can do. If you cut your prices, you make less. If you raise your prices, your competitor will begin to make belts again. Competition has driven the price down to $9, where supply and demand balance at 90 belts a week.

The buyers of the belts are naturally very happy with this state of affairs. You are not. Soon it would occur to you to come to an agreement with your competitor. You won't make handbags, which are his specialty, if he won't make belts. Perhaps all the leatherworkers in the area could quietly get together and assign each other the various leather articles most in demand. Each of you can now charge as much as you like, which is great for you and bad for the public. (At least, you can until someone else learns leatherworking and begins to compete with you.)

Many industries in the economies of medieval Europe were run this way. By means of what was called the guild system, producers divided up the market among themselves. They even influenced governments to pass laws to keep anyone who was not a member of the guild from practicing a trade. In this way, the supply of goods was strictly limited to keep up the price. Customers had to pay more for their goods than they otherwise would have had to, and since the whole society could not be completely regulated

in guilds, people who produced items not protected by the law from competition were at a severe disadvantage. They had to pay more for their goods than would otherwise have been the case, and they were forced to compete with all the other people who had been kept out of the guilds.

Surprisingly enough, the attempt to "outmuscle" the system was not good for the guild members either, in the long run. People would naturally try to avoid paying the high prices the guilds demanded. So they would search for substitutes. Always, they would be one step ahead of the guilds and of the government, which tried to outlaw the substitutes. The result was some very strange laws. For instance, to encourage the making of wool by the weaver's guild, a law in medieval England required every corpse to be buried in a woolen shroud! It is hard to regard this system as making efficient use of either materials or human beings.

Besides, we should recall the effect the law of supply and demand had on the producers we described earlier. As a result of the drop in prices, the cheesemaker had to become more efficient and reduce her costs, and the cattle rancher had to try new markets for his goods. The pressure of prices forced them to continue to work to make their businesses more efficient. If the perfect car had been invented, as well as all the perfect ways of making it at the least possible price, perhaps competition would not be necessary. But the great strides our own economy has made in the last century should convince us that some improvement is always possible.

In fact, business competition is so important for the good of the entire economic system that our society makes it <u>illegal</u> (usually) for producers to get together and agree to limit competition. Enforcing this law is a constant struggle, because it is often very difficult to tell when an agreement to limit competition has been made. The government even takes special steps to encourage competition, even when nothing illegal has been done to decrease it. In the short run, competition makes it difficult for individuals to make a profit, and it often creates duplication of effort. In the long run, however, competition encourages each producer to invent substitutes that are easier or cheaper to produce. Thus the economic diversity created by competition leads to a more efficient use of society's resources, and more wealth for the society.

Planning. The free market system we have been describing is obviously a very "sloppy" system. It seems to be based on trial and error--or pure chance. But a closer look shows that a great deal of planning is going on.

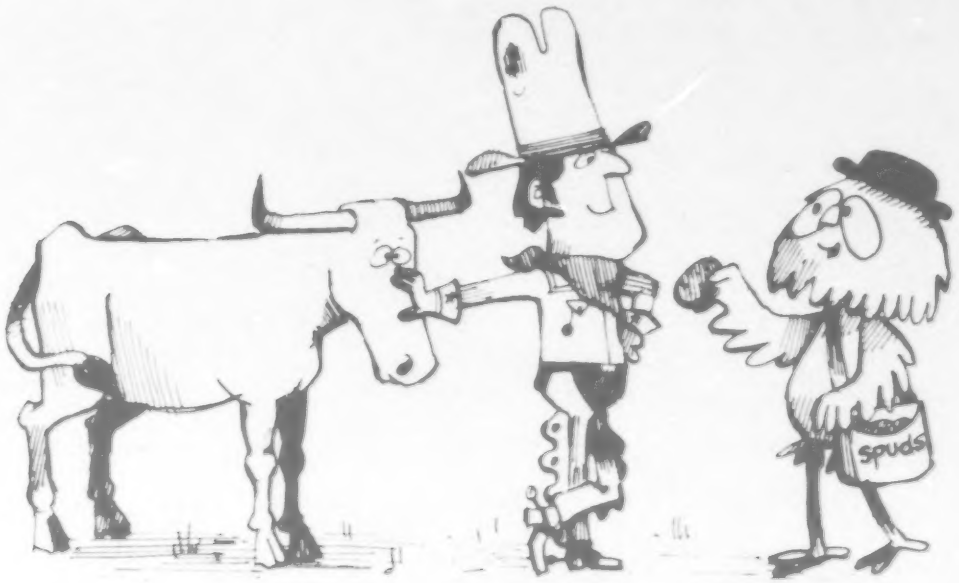
The most basic form of planning in this system is planning for adjustment. Human beings constantly learn and experiment in their economic life. In the example of the belt-maker, we spoke of his changing his prices to find the "right" price at which he could make the most profit. He could discover this price, or come quite close to it, just by a tour of the shops that already sell belts, and by computing his own costs. He could then pre-plan his whole operation, down to a few small adjustments. Of course, once he gets started in business in a growing system, he must be prepared to review and change his plans from time to time. But his sales and costs will give him notice of when to make changes.

Another, more dramatic kind of planning is also at work. Most people, when they begin a business or start to sell their labor, try to pick out a product or an industry which offers them good opportunity, as well as good immediate rewards. Some people even go so far as to ask themselves, "What goods and services are not available now but would be in demand if they were?" and then set out

to invent these. They may study closely the subsystem of a single manufacturing process, to discover ways to shorten it. Or they may look carefully over new products and services in one subsystem of the economy, to try to find ways in which these innovations could be transferred to other subsystems. Finding a new invention and designing ways of making the new invention more useful are the results of rather long and careful planning. As a result, such inventions are ... the property of their inventors by means of patents. In that way, the inventors can reap the rewards when they finally do succeed in producing something useful.

Surprisingly enough, finding ways to distribute an invention is often more valuable than making the invention. Elias Howe made the first usable sewing machine. But his invention was a very expensive, hand-made machine. It did little to meet the demand for cheaper clothing. Isaac Singer, however, found a way of making sewing machines with machines, instead of by hand. Although Singer had to pay Howe for the use of his patent, Singer was able to make a far greater profit than Howe because he was far more successful at actually filling the demand for easy sewing. And Singer went one step further. He invented the system of buying on credit, in which the buyer pays for an expensive item in monthly installments while he has the use of the item, instead of having to put down a lump sum beforehand.

Brokers of various kinds often invent solutions to problems of distribution, or getting goods to the people who want and need them. It is obvious that someone who buys potatoes in Idaho, where they are plentiful, and ships them to Texas, where potatoes are few, is doing both the customers in Texas and the farmers in Idaho a useful service. His planning is rewarded with profits. And in



"A potato Broker moves the vegetable... to places where they are scarce"

some cases, the profits may be quite high. After all, there are bound to be some times when the broker's plans will flop, when he will be stuck with goods for which there is little demand, and will have to sell for under his cost. He might "plan" for a shortage in one place, only to find

that the crop came through after all, or a substitute has been found. If he is to continue performing his service, he must make enough on the successful plans to permit him to pay for a few blunders (not too many, of course).

"Transporting" goods through time is also a service to the economic system as a whole. The potato broker moves the vegetables from places where they are plentiful to places where they are scarce. He could also buy them and store them till later, "moving" them from times when they are plentiful to times when they are scarce. The Bible story of Joseph tells of this kind of brokerage through time. Joseph predicted seven years of good harvests, and then seven years of famine in Egypt. He told the Pharaoh of Egypt to store food from the "good" years to use in the "bad" years. When Joseph's prediction came true, the Pharaoh could hardly reward him enough. After all, by his planning he had saved an entire country from starvation. For accurate predictions over the long run, many competing brokers are more likely than just one to guess right and keep goods distributed within the economic system--both geographically and in time. The competition between brokers also helps keep the costs of brokerage down.

The planning we have described here is decentralized planning, carried on by individuals or companies in the economic system. Each one studies the subsystem in which he hopes to participate, computes his costs, guesses his

future price, and also calculates his risk--what he can afford to lose if his plan fails. As we saw in the first half of this chapter, even in a simple barter economy it is difficult for anyone to be sure of his price, since it depends on the costs of the other members of the system. And how much a person might be willing or able to risk depends on his own situation and personality. So the individual planner's calculations are tricky. But it would be quite impossible for another person to gather the information and do the calculation for him.

Decentralized planning is quite sloppy. First, it involves what seems to be waste, since so many plans fail. American companies introduce hundreds of new foods every year, and quickly discontinue them. What happened to all the bookkeepers who learned manual accounting methods just before computers were invented? Another criticism of decentralized planning is, oddly enough, that it succeeds too well at times. Pocket calculators are a good example. Within 5 years they became inexpensive little gadgets that just about everyone could own. The fast pace of this change is upsetting to people. "Will human beings forget how to add and subtract all because of some crazy computer inventor?" they ask. "Who is he to foist his idea on the whole society?"

Although an invention sometimes brings on rapid change, we should not lose track of the fact that, in a

market system, an invention can only become common enough to be a problem because many members of the system want and need it. No single member of the system plans the change, but it is "planned" nevertheless. The inventor plans his invention, and offers it to a company for sale. The company may or may not decide to manufacture it, depending on how it thinks the invention will succeed. When it is produced, the invention must be distributed, and brokers will test it against their other plans. Finally, customers will see how the invention assists their plans before they buy it. At any step of the way, the invention might be killed. And if it starts having a bad effect in one subsystem, people who notice the bad effect can stop using it, without having to try to control the other subsystems in which the invention is spreading.

Central planning of an economy is often inefficient because a single part of the whole system must do all the planning which is divided among many members of a market system--an enormous set of calculations! Besides, once a gadget has been invented or a new product introduced, the central planners are naturally unwilling to take a loss if it does not work too well or is expensive to produce. They will see their pet project through, have it produced and distributed, and occasionally even try to force people to buy it, by forbidding private manufacturing or importation of substitute goods. In this way, a

"neat" system may spend a lot of labor and materials producing something that only partially fills the demand. In addition, the new gadget is tried out on the whole economy at once. It may severely damage one subsystem long before the central planners of the entire system take notice and stop its use.

System Similarities. Now that we've covered some of the basic features of a market-type economic system, let's see if it has any similarities to the ecological systems discussed in chapter seven.

1. Healthy ecological systems have a lot of diversity. The same thing is true of economic systems. A society that has many different kinds of people with many different kinds of skills is in a better position to cope with

"Many different kinds of people with many different kinds of skills..."

change. If a change makes a particular set of skills less useful, it will affect fewer people. If a new problem crops up, a diverse society is more likely to have people with the ability to cope with it.

Furthermore, a society is more adaptable if it has many different economic organizations of many different kinds. Organizations can be big, middle-sized, or small; private or public; profit-making or non-profit; adventurous or conservative; and concerned with farming, mining, manufacturing, or providing services, among other differences. If a country or region's economy is dominated by any particular organization or type of organization, the whole economy can be hurt badly by any problems that develop in that area. For example, Chile's economy is dominated by a few big copper mining companies. When a world over-supply of copper developed a few years ago, the price of copper dropped and Chile's economy was devastated. The same thing happened to countries that specialized in growing rubber trees when synthetic rubber was invented.

The society with many types of organizations is also more likely to have one that is just right for coping with a new problem or taking advantage of a new opportunity. If giant IBM isn't interested in developing pocket calculators, that's okay, because little Texas Instruments <u>is</u> interested. If the government-owned postal service does

a bad job of delivering parcels, people can still get them delivered by private companies like UPS, and so on.

2. Efficient ecological systems often look sloppy and wasteful. The same thing is true of economic systems. Some of this is the price of diversity. A species tries out many different combinations of genes; some work and some don't. A business tries many different kinds of products; some work and some don't. There are many different kinds of cars sold because people have many different needs and preferences. And so on.

Much of the "sloppy" appearance is also due to normal feedback cycles. When frost killed coffee trees in Brazil, the price of coffee shot up, so people drank less coffee or switched to tea or other beverages. Two years later, the coffee supply recovered, the price dropped, and people switched back again. The big price fluctuations look sloppy, but they really represent the most efficient way to cope with a fluctuating supply.

Some of the "sloppy" appearance is also due to the reliance on market prices instead of "intrinsic values." Few people would claim that Star Wars was an artistically better movie than, say, A Man For All Seasons, but it certainly had a much higher market value, since far more people were willing to pay to see it. This strikes many people as unfair, but it is the most practical way to run an economy.

The market system also rewards a lot of plain luck. The person who buys a farm and then finds out he is sitting on an oilfield gets just as rich as the person who buys land because he is smart enough to figure out that the oil is there. The system doesn't care whether the reward is deserved or not. It simply provides the reward so that people will have a big incentive to find and develop a resource that is wanted by many people. In the long run, a sure reward will get more oil discovered than some system that tries to figure out who was smart and who was lucky, and reward only the smart ones.

3. Healthy ecological systems are highly decentralized. The same thing is true of economic systems. Private property is one example of this. Society, in effect, decides to let each person manage part of the society's resources. The most important resource you control in our society is your own labor. This is not true in many societies, where you could be told how and where to work, with no choices. Some people start off with more valuable resources

than others. Some people are smarter, some are luckier than other people. Some people also have much richer parents than others. This is a sloppy way of doing things which society tries to equalize in various ways. Public education is an effort to give everybody, no matter how poor, a chance to learn enough to contribute productively to his society. Inheritance taxes are there to try and make sure that all the wealth doesn't get too concentrated into too few people's hands. But too much equality hurts efficiency in a system, too. Providing the best for your kids is a big incentive for working hard and investing money so it will work for you, but if you aren't allowed to try to give your kids more than you had, there isn't much incentive to work hard or save for the future.

The main assumption in a market economy is that you will do a more efficient job of managing your own resources, your knowledge, skills, money, land, and so forth, than some government bureaucrat would, simply because it matters more to you. Also, every situation and viewpoint is different, but bureaucracies have to treat people and situations mostly alike, otherwise the job would be impossible. You know your own situation better than anyone else, and can afford to give it your completely individualized attention. Of course people make lots of dumb decisions, but the system works because, on the average, they make fewer dumb decisions for themselves than

other people would make for them.

There is also the matter of incentive. People will work much harder and more intelligently if they get the benefit from their own work. Slave labor is never as productive as people who work for themselves or for pay. In Russia, for instance, after the Revolution, they took the land away from the farmers and made them work on huge government-owned farms. Each family was left with only a tiny plot of land which they could use to grow a few vegetables for themselves in their spare time. Not surprisingly, the big collective farms have been a disaster, never producing anywhere near as much food as they could

have. The tiny private plots, on the other hand, have been extremely successful, producing many times as much food per acre as the government farms. The farmers worked

as hard as they could on their own plots because they could keep what they grew, and sell any extra. Ironically, the food produced in response to this "capitalist" incentive has often been the only thing that kept Communist Russia from having a major famine.

Finally, there are the problems of centralization. Big organizations are slow and take a long time to react to problems, new inventions, and changing circumstances. Economies are simply too complex for one central organization to understand and manage effectively. Approximately 100 billion economic decisions are made in the U.S. every year. One mistake at the top level (like a decision to make 100 harvesters when 200 will be needed to harvest all the crops before they rot) can throw the whole system off balance. Bureaucracies also favor "playing it safe." They are bad risk-takers, even when taking some risks will pay off in a big way.

4. Ecosystems are most vulnerable to things that distort information feedback channels. Spreading nerve poisons, artificial sex hormones, or chemicals which imitate or block natural odors can alter an ecosystem by distorting the system's information feedback channels. These things also have their counterparts in an economic system. There are two types of "information" in an economic system. The first is money, and the second is actual information, like

product reports, statistics, news, etc. If either one is distorted, it throws off the whole system.

If a company makes a profit in a free market, it should be because it has taken resources and produced something of greater market value out of them. Steel, labor, land, energy, and other things are used to create cars or refrigerators. Labor, recording gear, and vinyl are used to create hit records, and so on. The bigger the increase in value to society, the bigger the profit. But what would happen if a company didn't have to pay for some of the resources it uses? The value of the product a company sells might actually be lower than the value of the resources it uses up--a loss for society--but the cost of the resources might still be less than the selling price of the product--a profit for the company. The most obvious example is a process that uses clean water and dumps polluted water back into the river, such as those for making paper or soap. If the company doesn't pay the full cost (to society) of using that water, it can show a profit when society is taking a loss.

This is crazy! "Profit" is supposed to be a feedback signal that you are doing something right and that society wants you to keep on doing it. The problem is that part of the information about cost is being blocked out. The only solution is to make sure that producers have to pay all costs, including resources like clean air and water,

which used to be free. There are other "external costs" as well. A company whose process damages the health of its employees, but which doesn't have to take that into account, is benefiting wrongly. In cutting down trees for lumber, firewood, or paper, whole watersheds are disrupted, which will affect the well-being of many, many more people. Those who conduct their business in a way that leads to the extinction of valuable species also do not often take account of the "external cost" of their process. This is a political problem, as well as an economic one, and our society is still in the process of sorting it out.

Other feedback distortions can come from political efforts to legislate prices. Wage-price controls, rent controls, import barriers, etc., block important feedback signals, keep necessary corrections from being made, and generally make the situation worse. The government can also mess up the whole money/information system by

"Other feedback distortions come from political efforts"

fooling around with the money supply--inflating it, deflating it, or changing the rate of growth abruptly. Anything which changes the value of the dollar obviously distorts the "message" that each dollar carries. Say you buy a house for $30,000, and sell it for $60,000 twenty years later. It looks like you made a profit, doesn't it? But if the value of the dollar dropped more than 50% in 20 years, you actually took a loss! What's worse, you will have to pay taxes on the mythical profit, which just increases your loss!

Finally, there is outright censorship and fraud. If a company can lie to you in ads or make false promises in contracts, you don't have the information which is needed to make intelligent free market decisions. Similarly, if the government can lie to businesses or control the press, neither business nor the public can get the information needed to make those decisions wisely. The result is that people make poorer decisions, more resources are wasted, and the whole system becomes less efficient. To prevent this, society needs to do everything possible to keep information feedback as smooth, rapid, and honest as possible.

Summary

Market economies (private property, "free enterprise," "capitalism," etc.) are "good" systems--stable, flexible, resilient, efficient--for the same reasons natural ecologies

are "good" systems. This doesn't mean they are perfect and can't be improved. Many problems exist, such as sloppiness, unfairness, inequalities, and others we'll talk about in Chapter 10, but improvements require very careful systems thinking. "Obvious" solutions are often disastrous. There is a particular problem in trying to eliminate sloppiness and inequality. One big appeal of communism has been its claim to "scientific" and "rational" management of the economy. This is now a rather old-fashioned viewpoint. In real life, economic systems are much too complex for efficient centralized control. The result of trying to be "scientific" is the opposite--a much less efficient system in which everyone is worse off.

Socialism has a similar, but milder, effect. Eliminating private ownership doesn't make everyone equal, it just shifts the source of inequality from economics to politics. In the long run, people are less free and less well-off financially. The most attractive feature of socialism is an effective welfare system, but this is not incompatible (theoretically) with a market economy.

From a systems point of view, both socialism and Communism try to cure system problems by brute force. This is particularly so when dealing with the feedback loops that depend on people's natural desire to make life better for themselves. Both economic systems try to make people be unselfish, at the point of a gun, if necessary. A

well-designed market economy, on the other hand, tries to harness that self-interest with a network of feedback loops, arranged so that (most of the time) a person who does what is good for himself is also doing something that benefits the whole society.

One of the most important events in economic history was the publication in 1776 of a book called The Wealth of Nations by Adam Smith. Smith believed that if the government would just let the economy operate freely, people would do whatever was best for themselves and this would automatically lead them to do what was best for society. The experience of the 19th century proved that this was at least partly false. Few people today would want to live in a completely unregulated capitalist economy, just as few people would want to live in a completely untamed wilderness.

Today, the main economic debate is over how much the economy should be regulated. From a systems point of view, however, the important debate should really be about what kind of economic regulation to use. The traditional approach has been to increase the government's power to make economic decisions for people, either through bureaucracies or through government ownership. But the systems approach would be to change the economic rewards and penalties for various activities and then let people make their own choices. The goal would be to create a system in which Adam Smith's idea would actually be true, one in which the

decisions people make for their own personal benefit will almost always add up to decisions which are good for the whole society.

Chapter Nine: THE POLITICAL SYSTEM

As you may already suspect from reading the previous two chapters, many of the same principles that apply to healthy economic systems and healthy ecological systems apply as well to healthy political systems. Let's take a look at political systems--particularly our system here in the U.S.-- and see how they compare with other systems we have examined.

The most basic problem in any political system is the positive feedback of power. As we saw in Chapter 4, if one person has the power to make the rules for a society, or the power to compel others to obey, or

the power to decide disputes, that person tends to acquire more and more power until he has almost total power over everyone in the system.

In small groups, nearly total authority is not uncommon and may actually have certain advantages, so long as the "society" is small enough so that the leader can keep track of what the members are doing, and so long as they don't abuse their power. Most people would agree that a ship at sea or an army unit on the field of battle is safer and runs more smoothly if everyone in the group accepts the authority of a single leader. It is clearly impractical in most cases to call soldiers or sailors together for a vote on whether to attack the enemy or retreat, or whether to steer to port or starboard to avoid a collision. It is faster and more efficient to allow a single person to make the decisions.

The same principle may apply to a small village or a tribe. If a chief is successful at leading the tribe to victory in war, in choosing new hunting grounds, or in selecting a time to plant crops, the society will prosper and its members will probably be willing to grant the leader even more power.

But suppose the leader makes poor decisions, is lazy or unreasonable, greedy, unjust, or cruel? This type of leadership could damage or even ruin the society, as many examples in history will show. Hitler's oppression of the Jews in Germany during the 1930's, a policy designed

to unify non-Jewish Germans in opposition to a supposed internal enemy, resulted in the flight from Germany of many of her most talented and productive citizens. Many of them came to England and America and helped defeat Germany in World War II.

But people who have power do not usually give it up willingly, and they may try to suppress opposition and criticism by punishing or executing their opponents and critics. This is what appears to be happening today in such nations as Cambodia, Uganda, Russia, and Chile. The power of the leaders of these nations increases as they use their power to silence their opponents. Up to a certain level, perhaps, the leaders can be said to seek more power because they enjoy it, but beyond that level, their actions create so much opposition that they <u>have</u> to increase their use of oppression, just to stay in power. In other words, power does more than merely <u>encourage</u> the powerful to acquire more power; beyond a certain point, it <u>requires</u> them to do so.

Obviously, the positive feedback of power we have just described need not be unlimited. It has been limited and held in check in many societies by a number of processes painfully evolved over many centuries as people struggled to curb abuse of power by their leaders. The story of this struggle is a matter that has occupied the attention of

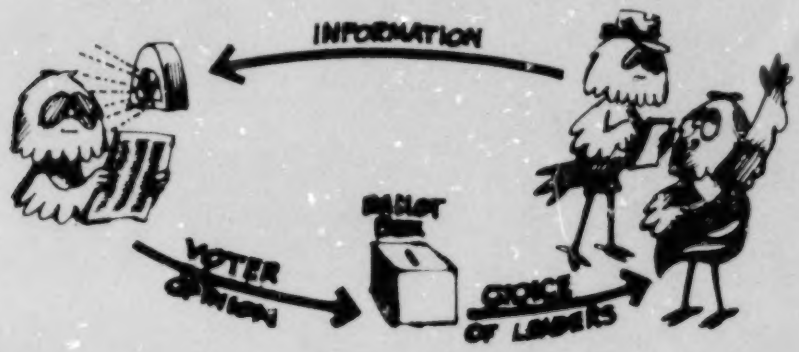
historians and philosophers for more than two thousand years, and still does, but we can only touch on it here. Our concern is how the results of that struggle have become part of our political system.

As we have seen earlier, the basic "natural" way to limit a positive feedback loop, such as the positive feedback of power, is to set up a group of negative feedback loops which resist excessive growth. The negative feedback loops that have been devised to control the growth of power include several familiar processes. Let's take a look at some of them.

Elections: Elections are the most obvious negative feedback loop in the political system. If public officials abuse their power, or fail in some way to satisfy the majority of the citizens, they can be voted out of office. However, an election must be honest and clean if it is to function as an effective negative feedback loop. This is not as simple as it sounds. It does not mean merely that ballots must be counted accurately and that no one be allowed to vote more than once. It includes several subtler elements.

It means, for example, that the voters must be allowed to obtain information about the candidates and the issues, and that other institutions, such as radio and television and newspapers, must be free to provide it. It means that voters must be free to discuss the issues of the election

among themselves. In other words, a clean, honest election, one that truly tests the opinion of the electorate, requires freedom of speech and freedom of the press.



"A clean, honest election that tests the opinion of the electorate requires freedom of speech and the press."

In addition, for an election to work, it is necessary that the citizens be allowed to vote. This may sound silly until you consider that, until recently, many states required voters to live in the state for a year or more before they could vote in a presidential election. People who had to move frequently from one state to another could thus lose their voting rights. In the past, furthermore, many election laws limited voting to property owners, or taxpayers, or to free white males over 21 years of age. Until fairly recently, vast sections of the population, including women, Indians, and blacks were systematically excluded from the election process.

But even if elections are free and open to all adult citizens, they still have their limitations. One is that they can be suspended or cancelled. Once elected and safely in control of a government, a ruler can declare himself king or dictator or "President for Life." There are many examples of elected leaders who seized more power than they were elected to hold, including Napoleon, Hitler, and the present day leaders of many of the nations of Africa, Asia, and South America.

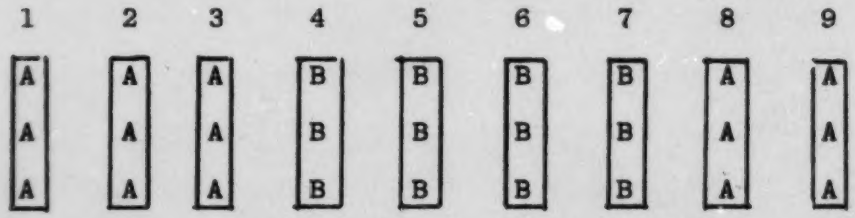
Another problem with the electoral process involves a typical positive-feedback power loop. Since the boundaries for the voting districts in each state are chosen by the state government, it is tempting for the party in power to draw the lines in a way that almost guarantees that it will stay in power, even if it no longer gets a majority of the votes.

A party can do this in two basic ways. The first depends on having districts with very unequal numbers of voters. For instance, if the people in the big cities usually vote Democratic and the people in rural communities usually vote Republican, a Republican legislature might be tempted to draw the district boundaries so that a city of 500,000 people and a town of 500 people would each get one representative to the legislature. This actually happened in many states and it got so bad in the first half of this century that the Supreme Court finally ruled that all dis-

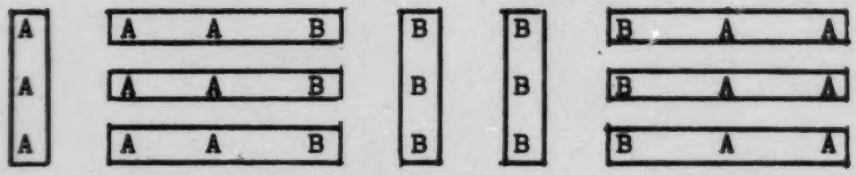
tricts for the same house of a legislature had to have about the same number of voters. The only exception is the U.S. Senate, where each state gets 2 Senators, even though California, for example, has 66 times the population of Alaska.

The other trick, called gerrymandering, is still in use. The basic idea is to draw boundaries so that your own party just barely wins in as many districts as possible. Notice, in the diagram below, that party A has a majority and would win 5 of the 9 seats with fair boundaries. If it controls the legislature, it could redraw the boundaries to give it an even bigger majority, as in the second diagram. If party B controls the legislature, on the other hand, it

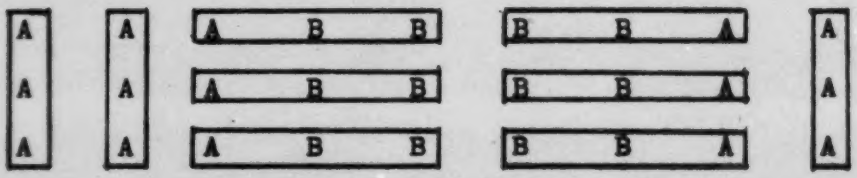
Possible Boundaries for Nine Electoral Districts



Neutral Boundaries: 5A, 4B



As party A might draw them: 7A, 2B



As party B might draw them: 3A, 6B

could draw the boundaries as in the third diagram and win six of the 9 seats even though it has only 44% of the vote!

It makes quite a difference, doesn't it? It's as if the football team in the lead at half time had the right to change the rules and choose the referees for the second half of the game. The only current limit on gerrymandering is a rather vague principle stated by the courts, which says that districts must be "reasonably compact." This prevents the winning parties from constructing absurdly snake-shaped or doughnut-shaped districts, but otherwise the practice remains uncontrolled.

So elections alone are not quite enough to provide negative feedback control over the positive feedback of power. Something further is needed, and that added measure of control is usually provided by a constitution which sets limits on the power of a government--even one headed by a lawfully elected leader. Some of the constitutional controls as they function in this country are: decentralization, separation of powers, and guarantees of individual rights.

Decentralization: The United States constitution sets careful limits on the amount of power given to the federal government by giving considerable power to the states. The states, in turn, have limited their own power by giving governing authority to local governments such as counties and cities.

Furthermore, under the constitution there are some things the federal government is forbidden to do without permission of the states; it cannot, for example, change the constitution. That can only be done with the cooperation of the states.

The U.S. is less decentralized today than it was when the nation was young and communication and transportation were slower and less effective, but decentralization is still an important characteristic of the political system and a restraint on the power of the federal government.

Separation of powers: By this we mean a decentralization of powers within one level of government. The constitution carefully divides the governmental powers between the Congress, the executive (headed by the President), and the courts. Essentially, Congress makes the laws, the executive branch carries them out, and the courts decide disputes concerning them. If Congress tried to grab power for itself by passing a law making every member of the Senate, say, a senator for life, the President could veto the proposed law; even if the veto were unsuccessful, the courts would say that the law contradicted the constitution, and they would strike it down. On the other hand, if the President or the justices of the Supreme Court do something illegal, Congress has the power to remove them from office through impeachment and trial.

Individual rights: Still another constitutional limitation on government power--that is, another protection of the negative feedback process--is the list of individual rights set forth in the amendments to the constitution. These are rights which even the federal government is not permitted to take away. For example, the amendments give all of us the right to criticize the government. They protect us against arbitrary seizure of our property. They ensure our right to worship as we choose, and prevent the government from establishing a state-approved religion to make its actions appear more godly. And they require the government to deal equally with each of its citizens, without giving special favors to one group or class, or denying them to others.

None of these rights is absolute, of course. The government can take possession of a person's property to build a road, provided it pays a fair price, and it may collect a fine for failure to obey a law. Freedom of speech does not allow anyone to deliberately say or write untruthful and damaging things about another person. In short, both the rights and the powers in this kind of political system are limited and balanced against the rights of others.

The constitutional provisions regarding individual rights do more than subtract from government authority. They also help to ensure the existence of other factors we found in healthy economic and biological systems--fac-

tors such as "sloppiness" and "diversity." Freedom of speech and freedom of religion, by allowing each person to hold and voice his own views clearly, make for a less orderly social system than would be the case were everyone to hold the same views. But untidiness and diversity, as we have seen, are a necessary part of a flexible and efficient system. If unpopular ideas were punished in the interest of order and sameness, new ideas would seldom emerge and society would be less able to meet and cope with new situations and problems.

"If unpopular ideas were punished... new ideas would seldom emerge..."

Another untidy element of constitutional democracy is the opportunity it provides for disobedience to authority. If, for example, the President ordered the top generals of the Army to arrest the members of Congress and the Supreme Court and place Washington under martial law, the generals would probably refuse and would, instead, bring the President's

unlawful command to the attention of the public. (At least we hope they would!)

This goes to the very core of the meaning of individual rights and constitutional protection. Even if an army officer believed that he ought to disobey the President, he would be afraid to do so unless he knew that he would be safe from retaliation and that the President could not immediately have him court-martialed and shot.

In the long run, the survival of limited government authority depends on the willingness of most people to obey the rules most of the time. Only in a police state or military dictatorship are there enough policemen to control a population if a large part of it does not want to be controlled.

But at the same time, this system of limited constitutional authority requires that most people feel reasonably confident that they can exercise their rights without government retaliation. The tendency of power to increase depends a great deal on the ordinary person's fear of offending people in power. Anything which reduces that fear weakens the positive feedback loop and helps keep the growth of power under control.

The similarity to the biological and economic systems should be apparent by now. In a biological system, the population of a species increases by positive feedback: the more rabbits are born, the more there are to give birth

to more rabbits. But populations are also limited by negative feedback: more rabbits means more food for lynxes which results in more lynxes, and consequently, fewer rabbits.

In an economic system, a firm increases its investment so that its profits will increase and, as profits increase, the firm is able to increase in size. But as its profits and size increase, other firms will be attracted to the field to earn some of the same profits and the competition will reduce prices and, consequently, profits.

In our political system, the increase in power by one part of the system is held in check by competition from other parts of the system. If the President asserts too much authority, the Congress will respond by passing laws limiting that authority, or by reducing appropriations and depriving the President of funds. There are similar checks on Congress and the courts.

Diversity and decentralization also strengthen the political system just as they do in economic and ecological systems. Different levels of government perform certain functions more effectively than others, and some states may be quicker to undertake bold experiments than others.

It makes more sense, for example, for a local government to decide whether or not to install a stop-sign at an intersection than to have that decision made in Washington. And it is generally healthier for, say, Pennsylvania to embark on a new method of funding public education than for all states to try it out simultaneously. If Pennsylvania is

successful, others will imitate her; if she is not, those who have adopted a wait-and-see attitude have lost nothing.

Another element our political system has in common with other systems we have examined is a variety of feedback times. The authors of the Constitution wisely perceived the importance of varying terms for different elected offices: two years for members of the House of Representatives, four years for the President, six years for Senators.

This ensures that some elected officials will be more responsive to short-term public opinion while others will be more sensitive to the long-term welfare of the nation. And it helps ensure more continuity in government than would be the case if the entire government could be changed in a single election.

The problems encountered by constitutional democracy are also similar to the "problems" encountered by the other systems. One is that the untidiness in the way decisions are reached or policies are formulated often means that solutions to pressing problems are less than perfect. In a democracy, political compromise is natural and usually desirable. But it is difficult for a governmental agency to "bite the bullet" and choose between two courses of action, either of which would be better than anything in the middle, but both of which would be extremely unpopular with a large number of people.

Sometimes either extreme would be better than compromising on the middle course

For example, many people think that it would have been less costly in terms of lives and money and would have brought results more satisfactory to everyone if the Viet Nam war had been either waged to win, or not waged at all. What actually happened was a compromise which contained the least desirable elements of both alternatives and the best of neither: the war was fought piecemeal and half-heartedly, with the result that the United States was not only defeated, but humiliated, and the suffering inflicted on the Vietnamese people was far greater than it would have been had the United States either stayed out or sought all-out victory. Democracies are not always able to choose between "either-or" solutions.

There are many other situations where democracies find it difficult to take decisive action. The widths between the tracks of early railroads were determined by the gauges of existing mine trains, and even though it was soon recognized that wider gauges would have been safer and more efficient, the change-over was said to be too costly. Had the conversion been made when the railway system was still in its youth, it would have been paid for many times over by the resulting savings, but the change wasn't made because no one was willing to pay the initial costs.

Other examples include the metric system conversion and the setting of state and local boundaries. The metric system is cheaper and more convenient than the so-called English system of weights and measures, but few people are willing to face the initial costs of conversion or the temporary nuisance of adapting to a different system. As a result, the federal government has been increasingly hesitant to require or even encourage the use of metric units.

Similarly, state boundaries were fixed by historic accidents, and frequently follow the paths of major rivers, former national boundaries, arbitrary lines of latitude and longitude, and other demarcations which seemed convenient at the time when they were

drawn. The use of rivers to divide states from one another has split up metropolitan areas like New York, Washington, and St. Louis and made it difficult to deal with area-wide problems like transportation and air pollution. River boundaries have also led to disputes among states when rivers changed course and increased the difficulty in managing water resources and environmental systems.

It might have been more effective in the long run had state lines been drawn along the crests of mountain ranges which change very slowly, are generally thinly settled, and which often form easy-to-define divisions in the eco-system. Once the boundaries were drawn, however, they became almost impossible to change because at any one time there are important groups which would lose by the change.

There are other problems with American democracy which have emerged in recent years. Let's take a look at some of them.

Increasing centralization: You often hear it said that the federal government--Washington--is acquiring power and that the state and local governments are losing it. This is to some degree clearly true, and to some degree inevitable.

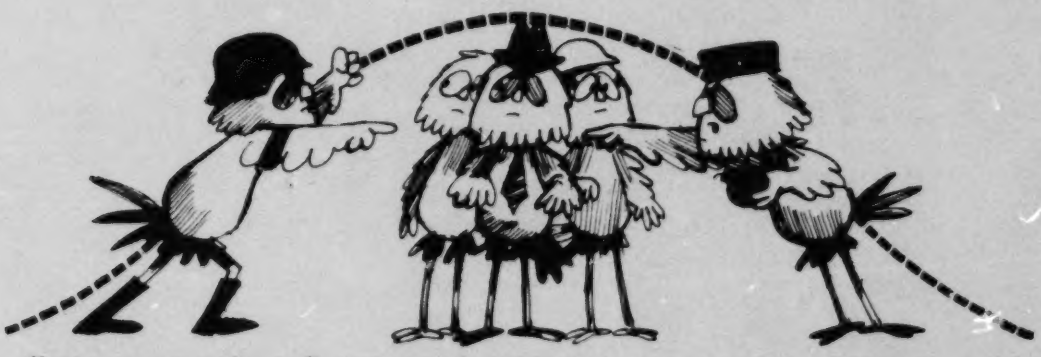
A number of factors encourage centralization. The increased speed and efficiency of transportation and communications tie the nation together more tightly into one big system. There is also a need to cope with the "commons"

effect we discussed earlier--such as the tendency of the states to compete with one another for new industry by offering lower taxes and more lenient anti-pollution laws. This can turn into the worst kind of cut-throat competition, where everyone gets hurt and nobody wins. The remedy is uniform, nation-wide, pollution control regulations and uniform rules on tax incentives for business, and only the national government can enforce that kind of uniformity.

But there are dangers in "big government." Big bureaucracies are hard to control and have no built-in negative feedback mechanisms to ensure their continued efficiency. A big business must continue to make profits or go broke, but a big bureaucracy can operate for years at a "loss" in terms of failure to deliver benefits equal to the cost of maintaining it.

Big government, furthermore, presents serious threats to freedom and flexibility. It tends to make rules which, because of its sheer size, are hard to change. It can also be used, and sometimes is used, to punish political enemies of persons in power. An example occurred when President Nixon instructed the Internal Revenue Service to audit the tax returns of his political enemies. Even though these people may have been innocent of tax evasion, the threat of investigation by the IRS was bound to have an intimidating effect upon them.

Fragmentation of public opinion: Democracy functions best when there is a fairly smooth distribution of political viewpoints, with the majority of voters holding opinions somewhere near the center, and only a few (Nazis and Communists, for instance) at the extremes. The winning candidate will often be the one who takes a position between the center of opinion and that of his opponent, in rather the same way that if you are asked to guess a number between one and ten, and someone else guesses seven, your best guess will be six.



"The majority of voters hold opinions near the center and only a few (Nazis & Communists) at extremes."

But the tendency some political observers see today is for political groups to break themselves into "one-issue" factions. These factions include environmentalists, civil rights advocates, women's rights champions, anti-pornography and anti-abortion groups, labor unions, and ethnic groups, to name just a few.

These groups provide politicians with the opportunity to win their support by promising to champion their particular

causes--even though no one cause, by itself, necessarily represents the view of the majority.

If an office-seeker gains the support of a sufficient number of special interest groups, he may win an election without ever having to make a commitment on other major issues of more general, but less intense, interest to the majority. This in turn could make it increasingly difficult to get a consensus in, say, Congress on matters of broad public interest.

Summary: Throughout this chapter, we have discussed constitutional democracy as a system. Systems thinking can help us decide what is "good" for the system--that is, what makes it stable, efficient, flexible, or viable--but it cannot prescribe what is good in a moral or ethical sense.

Systems theory cannot, for instance, help us decide questions of fairness such as whether it is "fair" for one man, who accidentally discovers oil on his land, to be richer than his less fortunate neighbor, or how much the government, through the tax structure, should attempt to reduce the difference between them.

Furthermore, systems thinking cannot determine what the balance should be between economic equality and political equality. They are not the same, and sometimes it seems that the more there is of one, the less there is of the other. In Communist China, for example, Communist party leaders enjoy a standard of living much higher than

that of the peasants, but the difference is less than the difference in the United States between a Rockefeller and a migrant farm worker. However, the difference in political power between the Chinese party leader and the peasant is enormous, whereas in the United States, the difference in political power between a millionaire and a farm worker is much less than the difference in their wealth.

Which system is better? The answer depends essentially on your own personal values and preferences. All systems thinking can do is help us explain why the society with somewhat more political equality and less economic equality will generally be both richer and more stable in the long run, particularly in a period of rapid change.

Systems thinking can also warn us of the "counter-intuitive" behavior of systems and help us understand the functioning of systems which appear, superficially, to defy common sense. But this does not mean that society must abandon "common sense" or common decency rules. Systematic analysis might show, for example, that the availability of welfare increases unemployment and reduces the incentive to work. But that is not a sufficient argument for letting people starve if they cannot find jobs.

What systems thinking does provide, however, is a way to examine new proposals. It may be decided, on moral grounds, that no one ought to be allowed to sell or trans-

port alcoholic beverages, but before society decides to impose such a restriction on itself, it should try to decide what the cost will be in terms of enforcement, additional crime, and general loss of respect for government. (When this was tried in the 1920's, the cost was found to be too high, and Prohibition had to be repealed.)

In short, it is important to know whether the price society will pay for some measure earnestly desired will be, in fact, the destruction of the system. To know that, however, we need a real understanding of how the system works, in all its complexity, and how it interacts with the other two parts of our life-support system--the natural environment and the economic system.

Chapter Ten: THE HUMAN ENVIRONMENT

So far, we've had a look at three systems, the natural environment, the economic system, and the political system, and we've considered how each functions and how each affects the human condition. What we have not looked at so far is how each of these systems affect the other two and how they all three interact as parts of the total human environment.

To say that these three systems are interrelated is not, of course, the same thing as saying that they always function smoothly together. Often, in fact, political and economic systems which seem to function well in themselves affect the natural environment in ways which eventually result in damage to all three systems and misfortune for

society. This has occurred over and over again in human history and the problem of fitting the three systems together is still with us today. It is an enormously complex problem which scientists and planners are just beginning to understand. But it is, nonetheless, a serious one--so serious, in fact, that it is becoming one of the principal concerns of human society the world over.

One of the reasons for the repeated failure of organized society to appreciate the interrelationship of the political, economic, and environmental systems is the obvious fact that they are really quite different from one another. Political and economic systems are human institutions. They are clearly more related to one another than either is to the natural environment. For instance, it is easy to see that a governmental decision to increase taxes will affect the economy. But it is often extremely difficult to see how a political and economic decision will affect the natural environment, or how the environment, in turn, affects politics and economics.

Being human inventions, the political and economic systems are at least theoretically capable of exercising foresight. People can anticipate the consequences of their actions, and act accordingly. The natural environment cannot. The various species of plants and animals that make up the biological sphere of the planet exist today because they are descended from other plants and

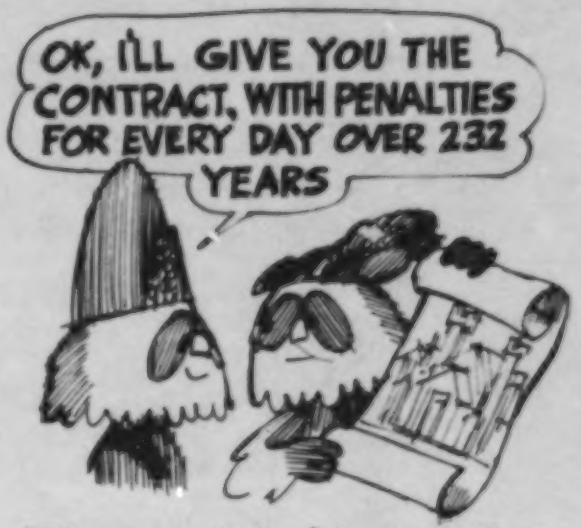
animals that survived the environmental conditions of the past, not because of any foresight.

In a way, we can say that the political and economic systems can think, but that the natural environment can only respond. However, political and economic systems have not always exercised foresight, even though they are capable of it. In fact, their lack of foresight is one of the leading problems in meshing the human systems with each other and with the natural environment.

Let's look at some examples. An economic system is capable of foresight, but characteristically this occurs only in the short run. People invest their earnings for a rainy day, or for a future return, but hardly anyone makes an investment unless it will yield a benefit to the investor within a few decades at the most.

There are occasional exceptions to this rule. The state of Israel began about two decades ago to replant the forests that covered large areas of that country in biblical times, even though the benefits will not begin to be realized until most of those engaged in the effort are dead. But the motivation for their actions is as much political and religious as it is economic.

Other exceptions rarely turn out to be purely economic in nature. The great Gothic cathedrals of medieval western Europe took as long as eight generations to complete, so that the man who laid the cornerstone was often a distant ancestor of the man who tiled the roof. But the benefits they sought were also more spiritual than economic.



"The great Gothic cathedrals took as long as eight generations to complete.

In general, then, it appears that foresight is more the realm of politics than economics. In a democratic political system--the kind that we have been primarily concerned with--foresight is only possible if the majority of the voters care about and understand long range problems and choose leaders accordingly.

The main problem with the political use of foresight is that most politicians cannot afford to look ahead any further than the next election. As a result, they tend to make decisions which are popular in the short run, even if they are harmful for society in the long run. An example was President Nixon's decision to impose wage and price controls during the summer of 1971, the year before

the end of his first term. Inflation had been proceeding at the rate of about 4.5 percent per year, and the decision was extremely popular. Public opinion polls taken shortly before the election of 1972 showed most people believed that Nixon was dealing well with the nation's economic problems. He was re-elected by a landslide.

After the election, the wage and price controls had to be lifted because they were causing more and more damage to the economy. When the controls were removed, the pressures which had been temporarily suppressed by the controls burst forth and inflation continued--at an annual rate of more than 10 percent! In other words, Nixon's anti-inflation program worked in the short run--just long enough to get him re-elected--but it made the problems much worse in the long run. In his memoirs, Nixon admitted that he knew ahead of time what would happen, but he was "forced" to go ahead anyway, to maintain his political popularity.

Another example of popular, but short-sighted, political decisions was the policy of the late Roman emperors of providing bread and circuses for the populace. The bread, distributed lavishly before elections, won votes for the man distributing it but resulted in increased taxes to pay for the bread. Since farmers and bakers were among those whose taxes were increased, the policy reduced the incentive to grow wheat and bake

bread. In short, it distorted the feedback system of the market for bread, making more food available to the poor temporarily but less available in the long run.

In considering how lack of foresight has created problems in the past, a word of caution is in order. It is easy and comfortable to say that past societies or past leaders were stupid or negligent when they failed to anticipate the consequences of what they were doing, but before we judge them too harshly we should keep in mind that they often had very few facts to draw upon. If we conscientiously put ourselves in their position, and try to perceive the world through their eyes, we will often be obliged to admit that in most cases we would have made the very same mistakes. Most of the problems generated by want of foresight have involved not negligence at all, but lack of information. They have been due, in a word, to ignorance.

Ignorance, in fact, has caused virtual sterilization of large tracts of once fertile farmland and made conditions right for more and worse floods in many parts of the world. For example, the ancient Mesopotamians constructed an elaborate irrigation system using the waters of the Tigris and the Euphrates rivers, in the area known as the "fertile crescent." Over a long period the water table in the flood plain rose to a few feet below the surface. From that level, it was drawn to the surface by

capillary action, like ink into a blotter. At the surface, the water evaporated, leaving behind the salt which had been dissolved in it. Regions of what is now Iraq, which were once among the most fertile lands in the world, are now so barren and so encrusted with salts that visitors must wear goggles to avoid snow-blindness.

Similar disasters have happened in many other irrigated areas since then. We know now that irrigation must be accompanied by drainage for the water not taken up by the crops. Yet even today we are allowing salt levels to build up in irrigated areas like southern California, and enormous irrigation projects are being planned without adequate drainage in countries like Afghanistan.

In 1927, disastrous flooding of the lower Mississippi Valley was found to have been actually increased by the system of levees constructed over the previous century and a half to keep flood waters within the river's banks. By forcing the river into a narrow channel, and giving it no place to escape, early engineers had created a succession of liquid traffic jams downstream. During the flood it was necessary to dynamite some of the levees and flood certain areas to keep other areas, like the city of New Orleans, from being wiped out.

Although the behavior of large rivers is still not completely understood, it is generally accepted today that

"During the flood, it was necessary to dynamite some of the levees."

the most efficient way to avert catastrophic flooding of the 1927 kind is to allow minor flooding along a river's entire length. In other words, a sophisticated study of the feedback loops involved in the river system shows that you can fight floods with floods.

This fact has proved difficult to translate into public policy, however. Owners of land on flood plains bordering the river have fought hard against regulations that would prevent them from building on the land and protecting it with levees. Their political influence has been enough to modify, and sometimes to stop, environmentally sound flood control measures.

Ignorance of the true nature of the feedback loops of a system shows up often in economic policy issues. For instance, many politicans believe that government spending programs are needed to reduce unemployment. But

many economists and systems analysts believe that the extra government spending increases inflation, which weakens the economy, which reduces the number of jobs available, which makes the unemployment problem worse instead of better. If we assume that the second view is correct, the politicians who act according to the first view will get caught in a "vicious circle": the more they spend to solve the problem, the worse the problem gets; the worse the problem gets, the more they spend to try to solve it.

In the process, both unemployment and inflation increase and the people in Congress and the White House can't figure out why their efforts to "stimulate" the economy don't work. In effect, they have turned a negative feedback loop into a dangerous positive loop without realizing it.

Even when political leaders are armed with sufficient knowledge and foresight to coordinate political activity with the economic system and the natural environment, the leadership sometimes finds itself powerless to do so. Often this occurs when the problem is outside the control of any one political system and there is no larger system with enough authority.

An example is the attempt to prevent the extinction of the great whales, which began shortly after the second world war with the formation of the International Whaling Commission. Although the commission is composed of

delegations from the major whaling nations, each of which has an interest in preserving whales for future harvest, the commission has been unable to agree on a workable conservation program and the world whale population has steadily declined.

For many years, the commission set annual hunting season limits by weight, a policy which simply encouraged whalers to hunt out the biggest whales, such as the blue and fin whales, first and go after the young and smaller whales only when the larger ones were gone. In 1933, the world catch of 29,000 whales yielded a total of more than 2.6 million barrels of oil. In 1966, whalers caught twice as many whales, but because the whales were so much smaller, they produced only 1.5 million barrels of oil.

"By 1966, the world whale population was so depleted that whalers could not even catch the allowable limit."

The commission's scientific advisors repeatedly warned that annual catch limits were being set too high, and their advice was repeatedly ignored. By 1966, the world whale population was so depleted that whalers could not even catch the allowable limit.

The situation became so serious that when the United Nations Environmental conference was held in Stockholm in 1972, 53 nations voted for a ten-year moratorium on all whaling and none of the nations present opposed it. The International Whaling Commission ignored that, too, and one valuable species after another is being destroyed.

Although some nations, like the United States and Canada, whose whaling industries constituted only a tiny proportion of their national economies, were able to curtail or halt their whaling, the large whaling countries like Japan and Russia were unwilling to sacrifice present advantage to future return. For Japan to reduce its catch voluntarily would simply mean leaving more for the Russians and in the long run the whales would disappear just as quickly. The situation is a perfect example of the tragedy of the commons we discussed in chapter six.

But it is not the only example. In the international arena, where there is no political system strong enough to exert its authority for the interests of all, cut-throat competition in the use of resources is commonplace. For instance, few nations are willing to undertake

population control, lest they sacrifice the political power that goes with growth in the short run. And for approximately the same reason--national power--no nation so far has been willing to give up nuclear weapons.

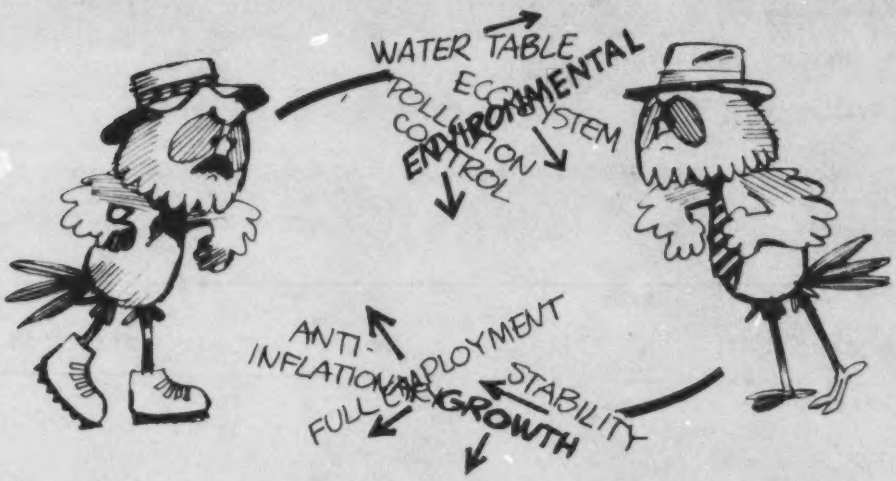
But it would be a mistake to assume that all, or even most, of the failures to arrange smooth interrelationships between the systems of the total human environment occur between the human systems and the natural environment. Many are between the political and the economic system.

Ignorance and lack of foresight play their roles in these failures too, and they often show up in the form of government activities intended to ease the pain that would occur were the effective, but sometimes brutal, free-market system allowed to function without interference. Examples include government regulation of airfares and freight rates aimed at preventing the airlines and trucking firms from undercutting one another, direct aid to large faltering firms like Lockheed Aircraft and the Penn Central railroad, and tariffs to protect domestic industry. In each case, government intervention, no matter how benign its intent, has the effect of reducing the incentive to operate efficiently and of increasing the price of goods and services to the consumer. Resources are wasted, the system operates less efficiently, and everybody ends up paying more for things.

The relationship between the political and economic

systems is imperfect in other ways. Corporations and unions, and the people who own and run them, use their wealth to purchase political influence, which they can use to create still more wealth. They impose costs on society, which society must eventually bear, such as when they pollute the air or water or obtain publicly-owned natural resources like timber without paying the true competitive price. Activities such as these distort the feedback loops in the economic system by creating artificial profits, and they distort the loops in the political system by making politicians responsive to factors other than the interests of the voters. But so long as large components of the economic system, like corporations and labor unions, rely upon government decisions for aid and protection, they will be tempted to try to influence those decisions.

The goal of understanding systems which comprise the total human environment should be to facilitate the feedback of information from one system to another. So far, the feedback connections have been imperfect, with the feedback between the ecological system and the political system the least smoothly functioning of the three.



"The feedback between the ecological system and the political system is the least smoothly functioning."

The provisional solution, which has come into being only within the past decade, is for interest groups, such as conservation organizations, members of the scientific community, or some newly-established government agencies, to provide information to politicians on potential environmental damage. Partly because of conflicts with other groups, such as businesses and unions, which benefit in the short run from exploiting the environment, and partly because of inadequate information about ecology, the feedback is still in need of improvement. And like the feedback loops between the two human systems, the economic and political spheres, it probably always will be.

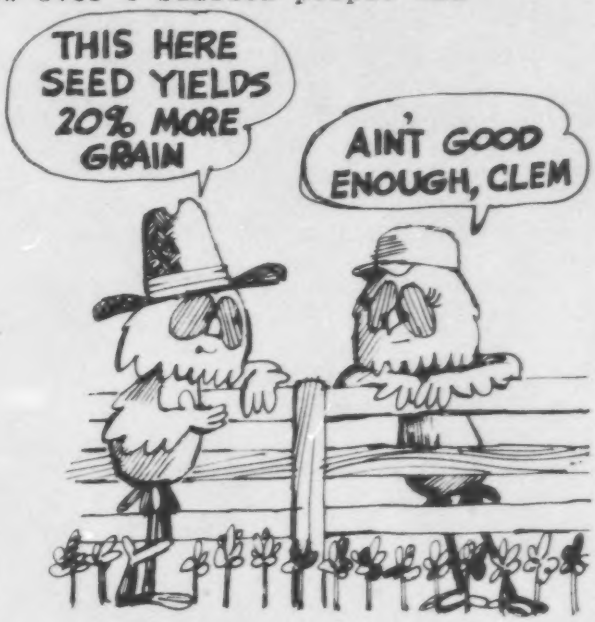
The "Macro-Problem": One reason that it is so important to get a better understanding of these interconnections is that we appear to be heading for a kind of system crisis point. There are six problems in particular--population, food, ecology, resources, economic growth, and war--which together create the possibility of a global disaster. The real danger is that the six problem areas are interrelated, and the traditional, non-systems "solutions" for each of the problems make the rest of the problems harder to solve. As a result, most current efforts to deal with these problems either don't work or make the whole situation worse.

Because these six problems are all interrelated and have potentially global effects, they are often referred to collectively as "the world macro-problem," or just as "the macro-problem." Some experts are convinced that we are headed for a major collapse -- with possibly several billion people dying from starvation, disease, and war -- during the next twenty years, unless we make some big changes in the way our political, economic, and ecological systems connect with each other. Even if these experts are wrong, the macro-problem is the biggest single threat to our quality of life, so it is worthwhile to look at the pieces of it.

At the core of the problem is a race between population growth on the one hand, and economic growth and

the increase in food production on the other. Obviously, if we double the world's wealth and double the population at the same time, the wealth per person does not change. Poor people would be just as poor as before, but there would be twice as many of them. In the same way, if population doubles and food production doubles, no progress has been made. The main result would be twice as many people who were malnourished, hungry, or actually starving. In other words, the production of food and wealth has to increase faster than the population to do any good, and the faster the population grows, the harder that is to do.

World population is now over 4 billion people and doubling about every 40 years. This means that if nothing happened to change the birth rate or the death rate, there would be around 8.5 billion people on the planet by the year 2020. However, there is little practical chance that food production can be doubled between 1980 and 2020. Almost all good



"There is little practical chance that food production can be doubled between 1980 and 2020."

land is now in use and much of it is actually being eroded away. Most of the obvious improvements in farming methods have already been made, and each additional step will cost more, take longer, and produce less. Modern farming also uses large quantities of scarce, expensive energy for things like fertilizer, tractors, and irrigation pumps. In addition, there is a growing world-wide shortage of fresh water.

If the birth rate stays high and food production does not keep up with it, there will not be enough food to go around. Even in good years, people will have to dig into stored food reserves. Then, when the first lean year hits, there will be small crops and no reserves, and the result could be a global famine on a scale never before seen, or even imagined. True, this would "solve" the population problem by increasing the death rate, but most people agree that it would be far better to reduce the birth rate instead.

A famine is not inevitable even if the birth rate stays high. It would be technically possible to increase food production fast enough to feed everyone for the next three or four decades, using large amounts of energy as well as advanced technology like hydroponics and ocean farming. However, it would be fantastically expensive. A great deal of money, manpower, energy, equipment, and other resources would have to be diverted from other

areas of the economy. This would drag down economic growth until it could not keep up with the population. The result would be more people, more food, and much more poverty. And at that point, the world would have to face another doubling of population, to 17 billion by 2060, with no practical way to pay for it.

Obviously, it is better to lower the birth rate than to bankrupt the world or let billions starve. Unfortunately, history has shown that birth rates don't start to drop until after average incomes rise above the poverty level.

The result is a perfect vicious circle: poor people have high birth rates, and high birth rates keep people poor. The richer nations of the world escaped this trap by pure luck: economic development in the West began several centuries before modern medicine and agriculture reduced the death rate so drastically. This allowed their economies to build up before population growth really got out of hand. In the poor areas of the world, however, modern medicine cut the death rate and started the population explosion before economic development had a chance to get started.

This race between population growth, agriculture, and economic development is at the core of the macro-problem, but the other three problem areas hold just as much potential for disaster. As population grows and

the world's farms and factories try to keep up, the demand for natural resources will also continue to grow. Unfortunately, the supply of many resources is strictly limited. Renewable resources like forests, fisheries, and fresh water supplies are already being used up faster than they can be replaced. Crucial non-renewable resources like oil, natural gas, silver, tin, aluminum, mercury, uranium, and zinc, are also becoming harder and more expensive to find. The easy sources have already been exploited. We now have to rely on smaller, poorer deposits and on deposits in inhospitable places like Alaska and the North Sea. As even these deposits run out, we will have to switch to more expensive or less effective substitutes, which will cut even more into economic growth.

Now suppose for the moment that we can solve the food and resource problems, and that the population and the economy manage to keep on growing. What will happen to the natural environment? A larger population means more sewage and trash to get rid of, more land to be cleared for houses and roads, more people jamming parks and beaches and invading wilderness areas. More food production means more pollution from fertilizers and pesticides, more marginal land cleared for farms, more erosion and silting of streams and rivers. Increased exploitation of natural resources means more invasions of

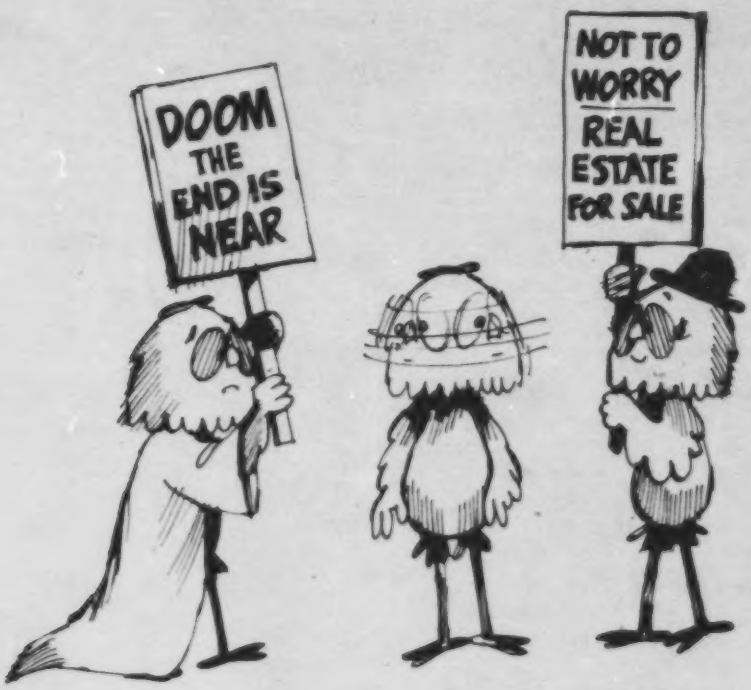
fragile ecological areas, more deforestation, more strip mining, and more oil spills. And economic growth means more factories and more pollution. In short, everything would combine to put the maximum amount of stress on the world ecology.

At some point, if that stress gets too great, the basic life-support system of the planet would begin to break down. Large areas might become barren, crops would be killed or contaminated by pollution, respiratory diseases and environmental cancers would increase, and eventually famine and disease would cause the system to collapse.

Finally, it is hard to imagine a world wracked by disasters without wars breaking out. When disasters happen, people look for scapegoats to blame and hatred can become quite irrational. The most likely targets will be rich industrial nations, particularly the U.S., and within a decade or two more than a third of the world's nations will have the capacity to build nuclear weapons.

There has been a lot of debate over just how dangerous this situation is for all of us. Some futurists (experts who study future possibilities for society) are pessimistic and believe that a collapse of civilization is inevitable. Others are quite optimistic, believing that new technologies will solve all our problems. Both points of

view are probably wrong. The extreme pessimists underestimate human resilience and ingenuity, while the extreme optimists underestimate the severity of the problem and greatly overestimate the effectiveness of technology as a solution.



Most serious futurists believe that the danger is real, but that a collapse can be avoided if people are willing to make an effort. They generally agree that scientific and technological progress will be very important, but that new technologies alone will not be enough. After all, many of the parts of the problem--like population growth, pollution, and resource depletion--were caused by scientific and technological progress in medicine, agriculture, and industry. It is precisely our success with science and

technology which has created the current enormous stress on our ecological, economic, and political systems, and it seems likely that more of the same kind of "success" will just increase that stress.

In this view, the only solution to the world macro-problem is a fundamental rearrangement of the world system, requiring a change in life-styles, economic goals, and kinds of technology. These are some of the specific measures--both social and technological--that have been suggested:

- Shift economic growth from goods to services. This is already happening to some extent in the rich nations, like the U.S., where more than half the workers work in education, research, government, health, finance, entertainment, and other service jobs, rather than in agriculture or manufacturing. Services generally require less energy and other resources, and create less pollution than manufactured products, so it will help a great deal if people can be persuaded to spend more of their money on education, good health, and good experiences, instead of on more manufactured things.

- Get more out of the energy and resources we use. The U.S., especially, has been called a "throwaway society," because we turn resources into products and then throw the products away so quickly. We could save energy, reduce resource use, and cut down on pollution and solid waste disposal problems if we made things that would last longer and could be recycled more easily. Indeed, our whole approach

to measuring economic success is biased: the gross national product (GNP) measures how much is produced, but not how much wealth people have.

• Substitute communication for transportation wherever possible. A phone call uses a lot less energy than a drive across town or a plane flight across country. New broadband communication systems, stationary-orbit satellites, and powerful, inexpensive computers will make it possible to greatly reduce travel and the bulk shipment of information in paper form. Electronic mail and news systems will soon allow us to eliminate 80% or more of the letters, reports, "junk mail," newspapers, magazines, and even books that are produced each year. Doing so would save whole forests worth of paper and a great deal of energy each year. Even a great deal of the internal paperwork that occupies most of the time of office workers in business and government can be done electronically instead, and office work itself can be decentralized to a great extent. Many businesses have already found that they can locate administrative offices wherever it is convenient for their employees, allowing people to cut down on commuting and the congestion in big cities. The question remains, however, of whether people will be willing to make the changes in social structure involved in shifting to a quieter, more decentralized, more information-rich/resource-poor life style.

• Make a massive effort to improve education in the poor nations of the world. Gifts of food and money just tend to support population growth without changing the basic situation, leaving people more helpless and dependent on outsiders. Education, on the other hand, helps lower the birth rate at the same time that it is increasing economic productivity and helping make people more independent and better able to handle their own problems.

• Establish an effective world-wide land conservation program, to help prevent erosion, salinization, over-grazing, and deforestation. The soil is the basic resource of all humankind, and its productivity must be maintained.

• Establish international agencies with real enforcement powers to control whaling and fisheries for the maximum sustained yield. It is foolish to destroy one species after another just for a few years' worth of profits.

• Similarly, establish stringent controls worldwide on both air and water pollution. This will please neither the rich nations, which produce most of the pollution, nor the poor nations, which want to industrialize as fast as possible. If it is going to be possible at all, the U.S. is going to have to play a leading role in developing resource-efficient, low-pollution technologies for the world to use.

• Finally, build up world grain reserves as fast as

possible. These reserves will be needed to alleviate the worst threat of famine, but they must be linked to each nation's efforts to control population and environmental damage. In other words, it must be understood that, in time of famine, food aid will go first to the nations which are reducing their birth rates and complying with conservation and environmental protection programs. Otherwise the food reserves would simply make the global commons more unmanageable and add to the size of the possible disaster.

These are only a few of the system changes that have been suggested as necessary. In the past 100 years, technology has quite abruptly turned the whole world into a "global village," but so far there is nothing equivalent to a village government with the power to prevent a "tragedy of the commons." The U.N. is a beginning, but it is barely more than a town hall where nations can meet to gossip and argue. A great deal more will be needed to cope with the many-sided macro-problem facing our global commons, and so it is up to some of the more powerful "citizens" of the global village, especially the U.S., to do everything they can to provide the leadership, the resources, and the systems thinking needed to manage the commons and prevent disaster. And since the possibility of a system breakdown threatens the survival and well-being of all of us, we each have a big stake in helping understand and manage the human environment as well as possible.

APPENDICES

APPENDIX A: SYSTEM NOTES

Ordinary education and common sense have usually been adequate for understanding immediate cause-and-effect in most areas of day-to-day human life. But for thousands of years, people have been puzzled, frustrated, and intrigued by the often contrary, paradoxical, and counter-intuitive behavior of the complex systems that surround them. Painfully learned lessons were usually encoded as proverbs, parables, stories, religious doctrines, and cultural taboos, so that others could avoid the unpleasant consequences of non-obvious system behavior.

Most of these lessons, of course, were pragmatic rules of thumb which applied only to specific situations, and the

people who applied them did not necessarily understand why they worked. For example, in India, no good Hindu peasant would consider killing a cow or bullock for food, even if the alternative is starvation. The accepted reason is that the cow is sacred in the Hindu religion. This custom seems irrational. Indeed, "sacred cow" has become a common metaphor for an irrational or foolish belief or custom. Only recently have careful system studies of the Indian environment shown that the custom is not irrational at all. It turns out that cattle play a vital role in Indian peasant agriculture. If some members of a village die during a famine, the village will still survive. But without cattle, the entire village will die. No doubt this was learned from many bitter experiences, and the prohibition against killing cattle was incorporated into the religion to make it easier for starving people to resist the temptation to break it.

In recent years, ecologists and system scientists have learned a great deal about how complex systems behave. In the process, they have discovered that, like the Hindu protection of cattle, many other apparently irrational folk customs have similarly valid bases. Some of these old rules of thumb have been updated and generalized in the writings of modern system thinkers, and some new insights about system behavior have been formulated. Together they make up a kind of modern "folk-wisdom" that can be helpful in coping with a complicated world.

What follows is a list of 28 of these system guidelines or rules of thumb gleaned from books, articles, speeches, and word-of-mouth. Many of them relate to or overlap one another, and have been grouped together accordingly. Sources, where identifiable, are given at the end.

Incidentally, these are rules of thumb, not absolute laws. The thinking behind each is sketched briefly, and you many find some more convincing than others. That's not really important, however, as long as they are provocative and help you make sense of some kinds of system behavior that don't seem, on first glance, to make any sense at all.

SYSTEM NOTES

1. Everything is connected to everything else. Real life is lived in a complex world system where all the subsystems overlap and affect each other. The common mistake is to deal with one subsystem in isolation, as if it didn't connect with anything else. This almost always backfires as other subsystems respond in unanticipated ways.

2. You can never do just one thing. This follows from rule #1: in addition to the immediate effects of an action, there will always be other consequences of it which ripple through the system.

3. There is no "away." Another corollary of #1. In natural ecosystems, in particular, you can move something

from one place to another, you can transform it into something else, but you can't get rid of it. As long as it is on the Earth, it is part of the global ecosystem. The industrial poisons, pollutants, insecticides, and radioactive materials that we've tried to "throw away" in the past have all too often come back to haunt us because people didn't understand this rule.

4. TANSTAAFL: There Ain't No Such Thing As A Free Lunch. Years ago, bars used to offer a "free lunch" as a way to draw customers. Of course, the drinks in those bars cost twice as much, so the lunches weren't really "free" at all. Similarly, in complex systems, what looks like the cheapest solution to a problem often turns out to be the most expensive one in the long run. TANSTAAFL is a way of saying, "Don't expect something for nothing, there's always a hidden cost somewhere."

5. Nature knows best. Natural ecosystems have evolved over millions of years, and everything in them has a role to play. Be very suspicious of any proposal to alter or eliminate an apparently "useless" part of the system. If it looks useless, that just means that you don't understand its function, and the risk of doing harm is that much greater. (For example, people have been draining "useless" marshes and swamps for centuries. Now, it turns out that these areas are vital for removing water pollution and as breeding grounds for economically important wildlife and fisheries.

An area worth $10,000 as dry land may produce $100,000 worth of fish a year as a marsh.) When in doubt, be careful, and always try to find a "natural" solution to a problem if at all possible.

6. It ain't what you don't know that hurts you; it's what you DO know that ain't so. Beware of false assumptions about system behavior. When we are sure of something, we usually don't bother to look for proof that it is true and we may be blind to evidence that it is false. We are much more likely to make really big blunders when we act on false assumptions than when we are uncertain and aware of our own uncertainty.

7. "Obvious solutions" do more harm than good. All complex systems use negative feedback to negate external changes in the system. If you try to change something in the direct, "obvious" way, the system is going to treat your efforts like any other outside influences and do its best to neutralize them. The more energy you waste fighting the system head on, the more energy it will waste fighting back, and any gains you make will be only temporary at best. Finally, if you try hard enough and long enough, you will exhaust the system's ability to fight back--at which point the system will break down completely.

8. Look for high leverage points. Nearly every feedback system has weak spots. These are almost always the control

points which measure the system's behavior and determine its response to change. The best way to change a system's behavior is either to change the "setting" of the control unit or to change the information which the control unit receives. If you want to make a cold house warmer, turn the thermostat up or stick an ice pack on it, but don't build a fire in the fireplace--it won't do any good.

9. Nothing grows forever. The exponential growth curves produced by positive feedback keep on growing only in mathematics. In the real world, growth always stops sooner or later, and the faster the growth, the sooner it will stop. If the Earth's human population could continue to grow at its current rate for another 7 centuries, we would be the only living things on the planet. After just ten more centuries, the mass of human bodies would outweigh the entire rest of the planet--an obvious impossibility. If energy use continued to grow at its current rate for another 400 years, the surface of the earth would be hotter than the sun. And at current rates of growth in food consumption, we would have to eat every living thing on the planet in a single year only 5 centuries from now. Obviously, these projections are ridiculous and the growth of population, energy use, and food consumption will stop long before such extremes are reached. The question is, how soon and in what way?

10. Don't fight positive feedback; support negative feedback instead. Don't poison pests, support their predators. Don't order people to have fewer children, make it more profitable for them to have small families instead. Don't ration energy, raise the price instead (and give the money back by cutting taxes somewhere else, like the social security tax). And so on. England used a version of this rule for centuries in European politics. Whenever one nation or group got too strong, England would throw its support to the weaker side. (Don't try to weaken your enemy, strengthen your enemy's enemies instead.)

11. Don't try to control the players, just change the rules. When the National Football League wanted to make football games a bit more exciting, it didn't order quarterbacks to throw more passes. Instead, it changed the rules slightly so that pass plays would have a better chance of working. If the league had gone the first route, teams would have looked for ways to evade the order, perhaps by throwing a few more short, safe passes, and the game would still have been dull. In the actual case, however, teams were aggressive about taking advantage of the new opportunities to pass. The same principle applies in economics, politics, science, education, and many other areas. If the system tries to make choices for people, the people will try to outwit the system. It is much more effective to change the "rules of the game" so that it is to most people's

advantage to make the choices that are good for the whole system.

12. Don't make rules that can't be enforced. If many people want to disobey a law and nearly all of them are able to get away with it, then the law will not be obeyed. But this gets people used to disobeying laws, and it reduces respect for laws in general. It also creates ideal opportunities for corruption, blackmail, and the acceptance of organized crime. A society that really gets serious about enforcing unenforceable laws can tear itself apart. (See, for example, the tremendous damage done by witchhunts, inquisitions, and civil wars that result from enforcing laws against thinking certain kinds of religious or political thoughts.) The same problem arises in business, government, and many other kinds of systems, where a higher system is weakened by trying to overcontrol lower subsystems.

13. There are no simple solutions. Real-life systems are big, messy, complicated things, with problems to match. Genuine solutions require careful thought for their effect on the whole system. Anyone who tries to sell you a simple answer--"All we have to do is....and everything will be perfect!"--is either honestly dumb, or dishonest and probably running for office.

14. Good intentions are not enough. Few things are more painful than trying to do good and finding out that you've done

a great deal of harm instead. Simple compassion and simple morality are inadequate in a complex world. The bumbling missionary causes tragedy because he follows his heart without using his head to try to understand the whole situation.

15. High morality depends on accurate prophecy. You cannot judge the morality of an action unless you have some idea of what the consequences of the action will be. According to this point of view, an action cannot be good if it has evil results, and everyone has a moral obligation to try to foresee, as well as possible, what the results of various decisions will be.

16. If you can't make people self-sufficient, your aid does more harm than good. This usually comes up in discussing problems of poverty or hunger, where temporary relief often postpones the disaster at the cost of making it much worse when it comes. It is not really an argument against helping, but an argument against half-way measures. Ghandi said the same thing in a more positive way: "If you give me a fish, I eat for a day; if you teach me to fish, I eat for a lifetime."

17. There are no final answers. As Ken Boulding put it, "If all environments were stable, the well-adapted would simply take over the earth and the evolutionary process would stop. In a period of environmental change, however,

it is the adaptable not the well-adapted who survive." This applies to social systems as well as natural ones. In a time of rapid change, like the present, the best "solution" to a problem is often one that just keeps the problem under control while keeping as many options open for the future as possible.

18. Every solution creates new problems. The auto solved the horse-manure pollution problem and created an air pollution problem. Modern medicine brought us longer, healthier lives--and a population explosion that threatens to produce a global famine. Television brings us instant access to vital information and world events--and a mind-numbing barrage of banality and violence. And so on. The important thing is to try to anticipate the new problems and decide whether we prefer them to the problem we are currently trying to solve. Sometimes the "best" solution to one problem just creates a worse problem. There may even be no solution to the new problem. On the other hand, an apparently "inferior" solution to the original problem may be much better for the whole system in the long run.

19. Sloppy systems are often better. Diverse, decentralized systems often seem disorganized and wasteful, but they are almost always more stable, flexible, and efficient in the long run than "neater" systems. In Boulding's terms (#17), highly adaptable systems look sloppy compared to systems

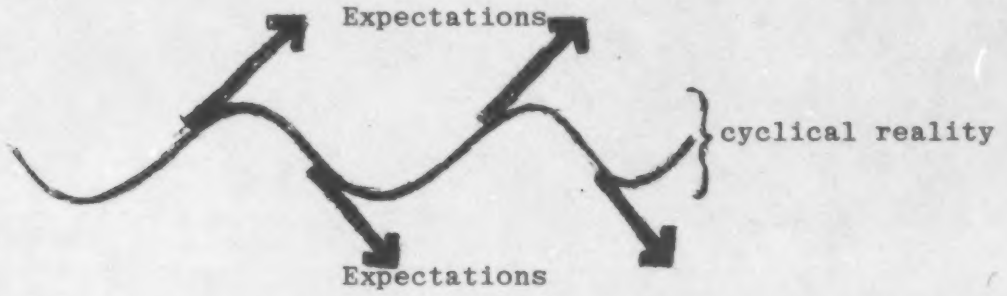
that are well-adapted to a specific situation, but the sloppy-looking systems are the ones that will survive. In addition, systems which are loose enough to tolerate moderate fluctuations in things like population levels, food supply, or prices, are more efficient than systems which waste energy and resources on tighter controls.

20. Don't be fooled by system cycles. All negative feedback loops create oscillations--some large, some small. For some reason, many people are unable to deal with or believe in cyclical patterns, especially if the cycles are more than two or three years in length. If the economy has been growing steadily for the last four years, nearly everyone will be optimistic. They simply project their recent experience ahead into the future, forgetting that a recession becomes more likely the longer the boom continues. Similarly, everyone is gloomiest at the bottom of a recession, just when rapid growth is most likely.

Highly visible job categories often fluctuate in the same way. When a temporary oversupply of workers develops in a particular field, everyone talks about the big surplus and young people are steered away from the field. Within a few years, this creates a shortage, jobs go begging, and young people are frantically urged into the field--which just creates a new surplus. Obviously, the best time to start training for such a job is when people have been talking about a surplus for several years and few others are entering

it. That way, you finish your training just as the shortage develops.

The problem is that most people have short memories and tend to project the recent past forward on a straight line. As a result you get this kind of pattern:



21. Remember the Golden Mean. When people face a serious problem, they tend to overvalue anything that helps solve it. They mobilize their energies and fight hard to solve the problem, and often keep right on going after the problem is solved and the solution is becoming a new problem. When most children died before their tenth birthdays, a high birth rate was essential for survival and societies developed powerful ways to encourage people to have large families. When the death rate is reduced, a high birth rate becomes a liability, but all those strong cultural forces keep right on encouraging large families, and it can take generations for people's attitudes to change. Like the man who eats himself to death as an adult because he was always hungry as a child, people tend to forget that too much of something can be as bad as too little. They assume that if more of

something is good, a lot more must be better--but it often isn't. The trick is to recognize these situations and try to swing the pendulum back to the middle whenever it swings toward either extreme.

22. Beware the empty compromise. There are also times when the middle ground is worse that either extreme. There's an old, old fable about an ass who starved to death halfway between two bales of hay because it couldn't make up its mind which one to eat first. Sometimes you just have to choose, because a compromise won't work. The only way to tell is to examine the entire system carefully and try to anticipate what the results of different decisions will be.

23. Don't be a boiled frog. Some systems are designed so that they can react to any change that is larger than a certain amount, but they can't respond to changes that are below that threshold. For example, if a frog is put in a pan of hot water, he will jump right out. But if he is put in a pan of cool water and the water is then gradually heated up, the frog will happily sit there and let itself be cooked. As long as the change is slow enough, it doesn't trigger a response. Sometimes a country can use this tactic to defeat an enemy in a patient series of small steps. Each step weakens the opponent a little bit, but is "not worth going to war over," until finally the victim is too weak to resist an attack. (These are sometimes

called "salami-slicing tactics." "Divide and conquer" is another version of the same thing.) While a healthy system shouldn't overreact to small changes, it has to be able to identify and respond to a series of small changes that will bring disaster if allowed to continue.

24. Watch out for thresholds. Most systems change pretty gradually. But some systems are designed to switch abruptly from one kind of behavior to a completely different kind. Sometimes this is a defense against the "boiled frog" problem. ("He's meek as a lamb until you push him too far. Then you'd better watch out!") In other cases, it's a way of avoiding "empty compromises" (#22). But most often it's because the system, or a subsystem of it, has exhausted its reserves for coping with some pressure on it. (See the discussion of exposure and heat-stroke in Part One.) This can be disastrous if you are relying on a system that has seemed able to absorb a lot of abuse and it suddenly collapses as a result of something apparently trivial. Democracies, market economies, and natural ecosystems are all prone to behave in this way. They seem so sturdy that we can kick them around, interfere with subsystem after subsystem, increase the load more and more, and they will always bounce back. But we can never be sure which straw is going to break the camel's back.

25. Competition is often cooperation in disguise. A chess player may push himself to the limit in his desire to defeat his opponent, and yet be very upset if he finds out that

his opponent deliberately let him win. What appears to be a fierce competition on one level is actually part of a larger system in which both players cooperate in a ritual that gives both of them pleasure. Not "doing your best" is a violation of that cooperative agreement. Similarly, the competitions between two lawyers in a courtroom is an essential part of a larger process in which lawyers, judge, and jury cooperate in a search for just answers. Businesses cooperate to keep the economy running efficiently by competing with each other in the marketplace. Political parties cooperate in running a democracy by competing with each other at the polls. And so on.

How do you tell cooperative competition from destructive competition? In cooperative competition, the opponents are willing to fight by the rules and accept the outcome of a fair contest, even if it goes against them. One reason extremist movements like communism or fascism are dangerous in a democracy is that they turn politics into destructive competition.

26. Bad boundaries make bad governments. Unlike most cities, St. Louis is not part of a larger county. St. Louis County surrounds the city and keeps it from expanding its city limits. As a result, the communities in the county have become parasites on the city, using the city's commercial and cultural resources but contributing nothing toward the cost of maintaining them. As long as there is a boundary

that splits the metropolitan area in half, and no government with authority over the whole area, the county will keep getting richer and the city will keep getting poorer until urban decay completely destroys it. Similar boundary problems afflict states, nations, ecosystems, and economic regions. As a general rule, the system with responsibility for a problem should include the entire problem area; authority must be congruent with responsibility, or a commons problem (#27) results.

27. Beware the Tragedy of the Commons. A "commons" problem occurs when subsystems in a competitive relationship with each other are forced to act in ways that are destructive of the whole system. Usually, the source of the problem is the right of a subsystem to receive the whole benefit from using a resource while paying only a small part of the cost for it. The solution is either to divide the common resource up (not always possible) or to limit access to it.

28. Foresight always wins in the long run. Solutions to problems affecting complex systems usually take time. If we wait until the problem develops and then react to it, there may not be time for any good solutions before a crisis point is reached. If we look ahead and anticipate a problem, however, we usually have more choices and a better chance of heading the problem off before it disrupts things. Reacting to problems means letting the system control us. Only by using foresight do we have a real chance to control the

system. Or: Those who do not try to create the future they want must endure the future they get.

Sources

Although some of these guidelines are associated with particular people, it is impossible to trace most of the concepts back to specific originators with any confidence. Rules 1, 3, and 5 were either coined or popularized by Barry Commoner. Rules 2, 14, 16, and 27 are associated with Garrett Hardin. #4 is associated with Commoner and science fiction author Robert Heinlein, among others. #6 is an old idea, but the words apparently come from humorist Will Rogers. #7 is associated with Jay Forrester. #9 is also an old idea; it has been emphasized by Isaac Asimov, Paul Ehrlich, Hardin, Forrester, and Donella Meadows, among others. #15 is a quote from John Platt's book, The Step to Man. The Boulding quote in #17 is from The Meaning of the 20th Century. Most of the rest are "in general use"--i.e., not especially associated with an originator or a popularizer. They have generally been paraphrased or re-stated for this book.

See appendices B and C for more detailed bibliographic references.

APPENDIX B: SOURCES FOR FURTHER STUDY

The best place to start a further investigation of general systems theory is Ervin Laszlo's The Systems View of the World. It and other good sources are described below, with the least technical and most readable ones marked with an asterisk. The last three sections--periodicals, films and filmstrips, and curriculum materials--will be of special interest to teachers who wish to incorporate systems concepts in their teaching.

In addition, there are some key names to be aware of, people who write well and think in a systems way:

Kenneth Boulding--Systems, economics, future of society.

Lester Brown--Food, environment, rich/poor gap, macro-problem.

Erik Eckholm--Environment, agriculture, resources, macro-problem.

Paul Ehrlich--Ecology, population, resources, pollution

Jay Forrester--System dynamics, computer models, economics, macro-problem.

Milton Friedman--Economics, world trade, government regulation.

Garrett Hardin--Ecology, population, food, macro-problem.

Margaret Mead--Anthropology, culture change, generational patterns, future of society.

Dennis and Donella Meadows--System dynamics, computer models, growth, the macro-problem.

World-Watch Institute--Home base for Brown and Eckholm, and the source of a steady stream of readable and reliable books, papers, and articles on world problems.

All of these people are important thinkers with solid scientific credentials; they are also all gifted writers and popularizers, with a knack for making complicated problems seem clear and interesting. You may not always agree with them, but you should find them always stimulating. Garrett Hardin, for example, delights in taking the most cold-blooded approach possible to difficult moral dilemmas. This offends many people, but it nearly always improves the rationality of the discussion. Some of the others write with considerably more warmth, but as a group they are always controversial and provocative.

General Systems Theory

*The Systems View of the World, by Ervin Laszlo. A brief, clear, non-technical introduction to general systems theory.

*The Cybernetic Society, by Ralph Parkman. "Cybernetics" is the study of self-regulating systems; it is often used as a synonym for GST, but the emphasis in cybernetics is primarily on negative feedback control loops. This book is a good, readable introduction to the practical uses of systems thinking--past, present, and future.

General Systems Theory, by Ludwig von Bertalanffy. Bertalanffy has been called the "father of general systems theory." This book is quite technical, but it is a good starting point for advanced study.

Introduction to Systems Philosophy, by Ervin Laszlo. Also quite technical, but a somewhat more readable and modern survey than Bertalanffy's book.

The Future of Society

*The Meaning of the 20th Century, by Kenneth Boulding. A slender classic and still one of the best introductions to the major issues facing modern society.

*The Step to Man, by John Platt. A collection of influential essays on science, politics, and social change from a systems point of view.

*Search for Alternatives: Public Policy and the Study of the Future, edited by Franklin Tugwell. Many modern "futurists" have a strong systems orientation. This book includes a number of important articles by people like Platt, Forrester, Ehrlich, and Toffler.

*The Futurists, edited by Alvin Toffler. Very similar to Search for Alternatives; together, the two books provide a fairly complete collection of the important background articles on the study of the future. Includes articles by Mead, Boulding, Arthur C. Clarke, and 19 others.

The Macro-Problem

*The Limits to Growth, by Dennis Meadows, et al. This brief description of a computer model of the world system astonished everyone by becoming a runaway best seller in 1972, with millions of copies sold in more than 20 languages. Its success was due partly to Donella Meadows's clear prose and to the fact that it was the first major attempt to make a dynamic model of such a large system, but the biggest reason for its success was its controversial conclusion: if we continue our current policy of indiscriminate growth, civilization as we know it will be destroyed in less than a century.

*Losing Ground: Environmental Stress and World Food Prospects, by Erik Eckholm. Most people concerned about world hunger have focussed on what is being done to increase food production and reduce population growth. Eckholm has quietly catalogued the many ways that our capacity to produce food is actually being reduced all over the world, through erosion, salinization, deforestation, desert-making, pollution, and environmental disruption. This is a horrifying and important book.

Population, Resources, Environment: Issues in Human Ecology, by Paul and Anne Ehrlich. The Ehrlichs' new book, Ecoscience, is THE authoritative text on population growth and the carrying capacity of the environment. However, its more than 1000 pages are a bit overwhelming. Population, Resources, Environment is briefer and less technical, and most people will find it the best introductory text on environmental issues.

Periodicals

The General Systems Yearbook. An annual collection of articles, ranging from moderately complex to extremely obscure. Published by the Society for General Systems Research.

System Dynamics Newsletter. An annual summary of current research, teaching ideas, and recent books and articles. Published by the System Dynamics Group at MIT.

Technology Review. This is the alumni magazine of the Massachusetts Institute of Technology, and its scope is much broader than its title indicates. It carries a regular column by Kenneth Boulding and frequent articles by Jay Forrester, members of the System Dynamics group, and others on system-related topics.

*The Futurist. A slick, bi-monthly magazine, dealing with trends and alternative future possibilities; many articles have a systems perspective. Published by the World Future Society.

(For additional periodicals see the periodical section of The Future: A Guide to Information Sources.)

Films and Filmstrips

Introduction to Feedback. Distributor: IBM/Modern Talking Pictures. Probably gives students a better idea of how

negative feedback works in 10 minutes than would a week's worth of reading assignments. Available free for schools and other educational organizations through Modern Talking Pictures. (Check the Yellow Pages or with any media librarian for the nearest distributor.)

Dimensions of Change. A 6-part filmstrip series, available with records or cassettes from Doubleday Multimedia. Topics include ecology, shelter, energy, food, mobility, and communications. Grade levels 7-12.

Cybernetics. A 22 minute color film from Contemporary/McGraw-Hill films. Deals with automation and computers.

Earth, No Vacancy: Limits to Growth. A 22 minute discussion of the computer model behind The Limits to Growth, featuring co-author Dennis Meadows. In color from Document Associates.

Looking at the Future: Systems Thinking. A 4-part filmstrip/cassette series from BFA Educational Media in Santa Monica, California. An excellent introduction for grades 6-12 to the disastrous effects of non-system, "obvious" solutions and the importance of a systems approach to problems.

Curriculum Materials

Teaching the Future and Futurism and Future Studies by Draper Kauffman. Both contain chapters on systems thinking. Teaching the Future has detailed descriptions of classroom activities and an extensive bibliography.

Our Working World. A systems-oriented social studies curriculum for grades 1-6, designed by Lawrence Senesh, and available through SRA (Science Research Associates). Even if you are not teaching at an elementary level, try to obtain the descriptive pamphlet for Our Working World from SRA. The pamphlet, New Paths in Social Science Curriculum Design, contains excellent flow charts and summaries of the fundamental ideas in economics, politics, social organization, culture change, social psychology, and law and justice.

Manual for the City Building Educational Program. By Doreen Nelson. In the early 70's, Doreen Nelson developed a year long curriculum for her 5th graders in Saugus, California. The curriculum completely integrated all activities for the year, including language arts, math, social studies, and science, into an interdisciplinary

study of the surrounding community and ecosystem. It was so successful as a way of teaching kids basic skills as well as more integrative forms of reasoning, that other teachers began adopting it and adapting it for other grade levels, and there is now an on-going Center for City Building Educational Programs near Los Angeles.

People and Technology. An excellent social studies unit for Junior High School students, using an interdisciplinary systems-oriented approach, but does not actually teach systems concepts. Available from EDC (Educational Development Corporation).

Making Changes. A three-part curriculum unit aimed at teaching creative problem solving designed for 8th and 9th graders by Research for Better Schools. Has a definite systems "flavor," but does not teach many systems concepts.

In addition, some excellent work is being done by Nancy Roberts and other members of the System Dynamics group at MIT. Roberts and her colleagues have been developing and testing curriculum materials and activities for teaching dynamic feedback modelling at elementary and secondary levels. At the time this is being written, the results are unpublished, but some materials may be available shortly.

The Guide to Simulations/Games, by David Zuckerman and Robert Horn. Studying and analyzing complex systems can get pretty abstract and difficult. It is much better to experience their behavior directly and observe first-hand their sometimes surprising interactions. Often the best way to do this is through simulations and simulation-games. Students can try out strategies in a simulation, see the results quickly, and try out different strategies, until they get a feel for how the system works. The Guide is an invaluable directory of hundreds of games and simulations on every imaginable topic. No school should be without a copy.

APPENDIX C: BIBLIOGRAPHY

Ackoff, Russell L. Redesigning the Future: A Systems Approach to Societal Problems. John Wiley and Sons, 1974.

Ashton, T.S., et al. Capitalism and the Historians. University of Chicago Press, 1954.

Ayres, Robert U. Technological Forecasting and Long Range Planning. McGraw-Hill, 1969.

Beishon, John, and Geoff Peters (eds.) Systems Behaviour. London: The Open University Press/Harper & Row, 1972.

Bell, Wendell, and A. Mau (eds.) The Sociology of the Future. Russell Sage Foundation, 1971.

Bertalanffy, Ludwig von. General Systems Theory. Braziller, 1968.

Boulding, Kenneth E. The Meaning of the 20th Century. Harper Colophon Books, 1964.

Bresler, Jack B. (ed.) Human Ecology: Collected Readings. Addison-Wesley, 1966.

Brown, Lester. The Twenty-Ninth Day: Accommodating Human Needs and Numbers to the Earth's Resources. W. W. Norton & Co., 1978.

Buckley, Walter. Sociology and Modern Systems Theory. Prentice-Hall, 1967.

Churchman, C. West. The Systems Approach. Dell Publishing Co., 1968.

Coombs, Philip H. The World Educational Crisis: A Systems Analysis. New York: Oxford University Press, 1968.

Daly, Herman E. (ed.) Toward a Steady State Economy. W. H. Freeman & Co., 1973.

Disch, Robert (ed.) The Ecological Conscience: Values for Survival. Prentice-Hall, 1971.

Eckholm, Erik P. Losing Ground: Environmental Stress and World Food Prospects. W. W. Norton & Co., 1976.

Educational Development Corporation. People and Technology. Boston: EDC, 1975.

Ehrlich, Paul R., Anne H. Ehrlich, and John P. Holdren. Ecoscience: Population, Resources, Environment. W. H. Freeman, 1977.

Ehrlich, Paul R., and Anne H. Ehrlich. Population, Resources, Environment: Issues in Human Ecology; 2nd Edition. W. H. Freeman & Co., 1972.

Forrester, Jay W. World Dynamics. Cambridge, Mass.: Wright-Allen Press, 1971.

Friedman, Milton. Capitalism and Freedom. University of Chicago Press, 1962.

Friedman, Milton. There's No Such Thing as a Free Lunch. Open Court, 1977.

Hall, Edward T. The Silent Language. Greenwich, CT: Fawcett Publishers, 1959.

Hardin, Garrett. The Limits of Altruism: An Ecologist's View of Survival. Indiana University Press, 1977.

Hardin, Garrett, and John Balen. Managing the Commons. W. H. Freeman, 1977.

Hardin, Garrett. Stalking the Wild Taboo. William Kaufmann, 1978.

Harman, Willis W. An Incomplete Guide to the Future. Simon and Schuster, 1976.

Kauffman, Draper L., Jr. Futurism and Future Studies. National Educational Association, 1976.

Kauffman, Draper L., Jr. Teaching the Future: A Guide to Future-Oriented Education. Palm Springs, CA: ETC Publications, 1976.

Laszlo, Ervin. Introduction to Systems Philosophy. Gordon and Breach, 1972.

Laszlo, Ervin. The Systems View of the World. George Braziller, 1972.

McHale, John. The Changing Information Environment. Westview Press, 1976.

McHale, John. The Ecological Context. George Braziller, 1970.

Malabre, Alfred L., Jr. Understanding the Economy: For People Who Can't Stand Economics. Dodd, Mead.

Marien, Michael. Societal Directions and Alternatives: A Critical Guide to the Literature. Lafayette, N.Y.: Information for Policy Design, 1976.

Martin, James. The Wired Society. Prentice-Hall, 1978.

Meadows, Dennis (ed.) Alternatives to Growth/I: A Search for Sustainable Futures. Ballinger, 1977.

Meadows, Dennis, et al. The Dynamics of Growth in a Finite World. Wright-Allen Press, 1973.

Meadows, Donella, et al. The Limits to Growth. Universe Books, 1972.

Meadows, Donella, et al. Toward Global Equilibrium: Collected Papers. Wright-Allen Press, 1973.

Miles, Rufus E., Jr. Awakening from the American Dream: The Social and Political Limits to Growth. Universe Books, 1976.

Mishan, E. J. Technology and Growth: The Price we Pay. New York: Praeger, 1969.

Nelson, Doreen. City Building Educational Program. Los Angeles, CA: Center for City Building Educational Programs, 1975.

Oltmans, Willem L. (ed.) On Growth: The Crisis of Exploding Population and Resource Depletion. Putnam's, 1974.

Ophuls, William. Ecology and the Politics of Scarcity. W. H. Freeman, 1977.

Parkman, Ralph. The Cybernetic Society. Pergamon Press, 1972.

Parsegian, V.L. This Cybernetic World: Of Men, Machines, and Earth Systems. Doubleday, 1972.

Passmore, John. Man's Responsibility for Nature: Ecological Problems and Western Traditions. Chas. Scribner's Sons, 1974.

Pattee, Howard H. (ed.) Hierarchy Theory: The Challenge of Complex Systems. George Braziller, Inc., 1973.

Platt, John R. The Step to Man. John Wiley & Sons, 1966.

Research for Better Schools. Making Changes. Philadelphia: RBS, 1978.

Rubin, M.D. (ed.) Man in Systems. Gordon & Breach, 1971.

Senesh, Lawrence. Our Working World: New Paths in Social Science Curriculum Design. Science Research Assoc., 1973.

Simon, Anne W. The Thin Edge: Coast and Man in Crisis. Harper and Row, 1977.

Toffler, Alvin. Future Shock. Random House, 1970.

Toffler, Alvin, (ed.) The Futurists. Random House, 1972.

Toffler, Alvin, (ed.) Learning for Tomorrow: The Role of the Future in Education. Random House, 1974.

Tugwell, Franklin. Search for Alternatives. Winthrop Publishers, Inc., 1973.

Wanniski, Jude. The Way the World Works: How Economies Fail and Succeed. Basic Books, 1977.

Watt, Kenneth E. F., et al. The Unsteady State: Environmental Problems, Growth, and Culture. University Press of Hawaii, 1977.

Wiener, Norbert. Cybernetics: or Control and Communication in the Animal and the Machine. The M.I.T. Press, 1961 (2nd ed.).

Wiener, Norbert. The Human Use of Human Beings. Avon Books, 1950.

Wilson, Edwin O. Sociobiology: The New Synthesis. Harvard University Belknap Press, 1975.

World Future Society. The Future: A Guide to Information Sources. Washington, D.C.: The World Future Society, 1977.

Zuckerman, David W., and Robert E. Horn. The Guide to Simulations/Games for Education and Training. Information Resources, Inc., P.O. Box 417, Lexington, MASS, 02173. 1975.